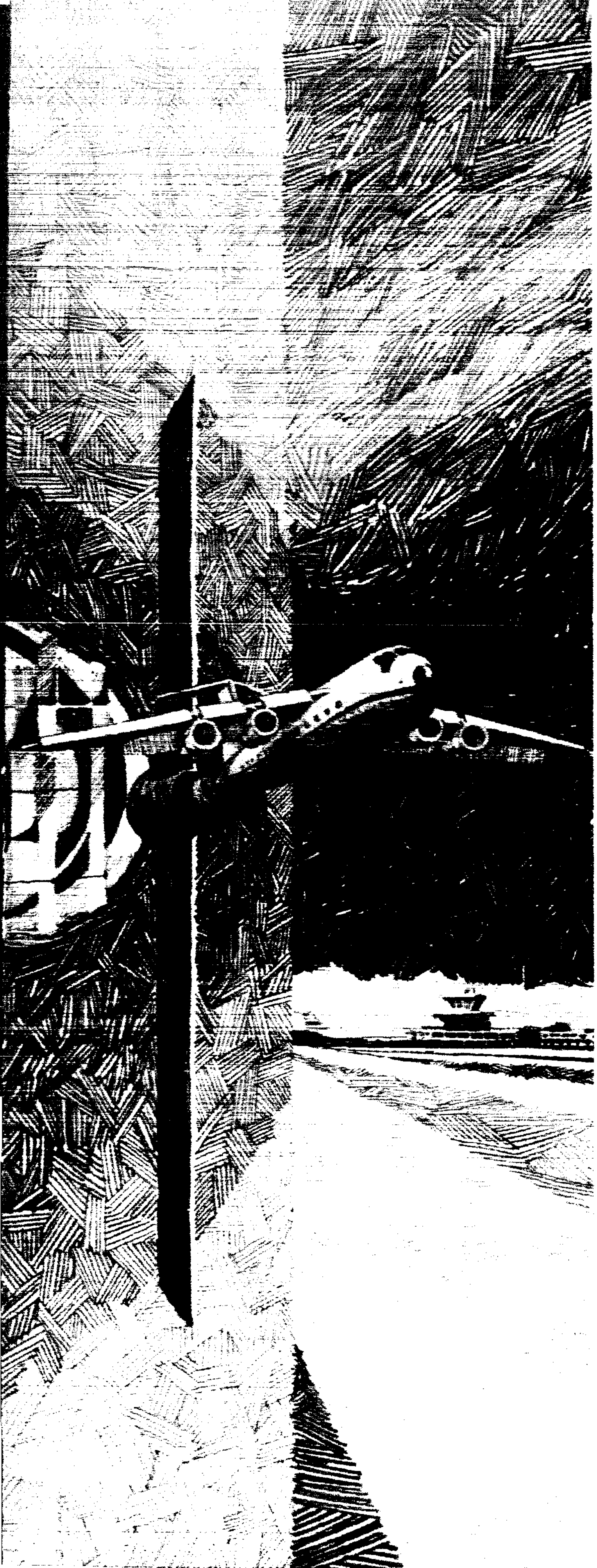

DOT TST-10-5
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JOINT
DOT-NASA

CIVIL AVIATION RESEARCH AND DEVELOPMENT POLICY STUDY

SUPPORTING PAPERS

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TABLE OF CONTENTS

1. INTRODUCTION

This document contains the results of a series of analyses made as part of the Joint DOT-NASA Civil Aviation Research and Development Policy Study.

The sections in this document cover a variety of subjects, some technical – which relate directly to civil aviation research and development – and some nontechnical – which affect the climate for technical innovation in the civil aviation industry and therefore determine whether the results of research and development will find application in the future. Figure 1.1 shows the interrelation between the sections. The sections on the left-hand portion of the figure (Missions and System Elements) form the technical foundation of the report, that is, the specific missions performed by civil aviation and the four system elements of each of these missions. In the analysis of a mission (such as commercial passenger service), each system element must be considered, and conversely, in the analysis of a system element (such as air traffic control), each mission must be considered.

Each technical section is based on analyses of the characteristics and growth to date, current problems, future requirements (demand for service), potential solutions, implications for R&D, and recommendations.

The first section of the report, "Systems Status and Potential," combines the missions and elements, so that they may be examined in the context of a total air transportation system. The structure, characteristics, and cost of an air transportation system that could efficiently satisfy the potential demand for air services in 1985 are presented.

Early in the Study, it became evident that one of the most serious problems facing civil aviation related to its impact on the environment. The degree to which civil aviation can solve its environmental problems (the most important ones being noise and pollution) will determine the degree to which it can grow to serve the Nation. A separate section is devoted to this subject.

Other nontechnical considerations affect (and in turn are affected by) civil aviation to such an extent that separate analyses were indicated. Two of these "nontechnical" sections address industry financial considerations and foreign competition to show the relationships between these factors and the health of civil aviation (and vice versa).

The Senate Committee on Aeronautical and Space Sciences raised the specific question of "the divergence of military and civilian aeronautical requirements." Because of this and the importance of military R&D to civil aviation, a separate section on the military contribution to civil aviation is included.

The "Policy" section addresses certain policy issues that transcend technology alone and are heavily involved with the nontechnical, or institutional, factors that affect the climate for technological innovation.

Aeronautical R&D – which resulted in significant advances in the various elements of aviation – together with other, nontechnological factors and policies have brought significant benefits to the Nation. The last section of this volume addresses these benefits and their relationship to research and development.

Although the sections are all interrelated and interdependent as shown in Figure 1.1, each section was intended to be a reasonably complete discussion of its subject. There is thus some redundancy among the papers. Many of the sections contain conclusions and recommendations based on detailed analysis of the specific subject area. The analyses and specific recommendations of this document formed the basis for the report of the Joint DOT-NASA Civil Aviation Research and Development Policy Study, published as DOT Report TST-10-4 and as NASA Report SP-265.

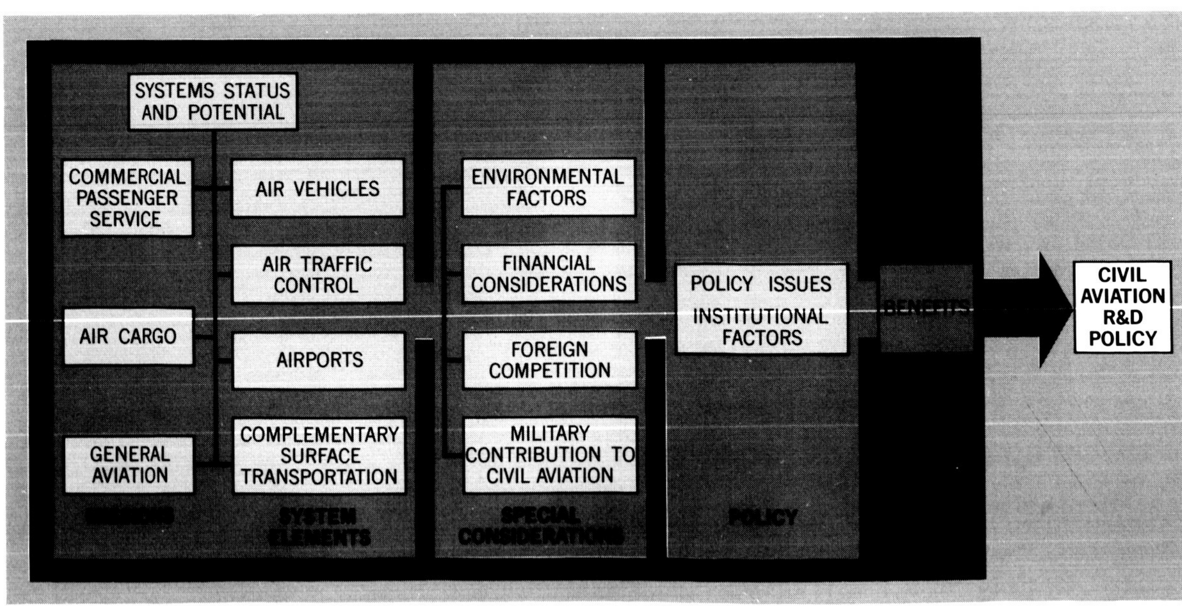


Figure 1.1. Civil Aviation Research and Development Policy Study structure.

2. SYSTEMS STATUS AND POTENTIAL

Systems Status and Potential

INTRODUCTION

For the purposes of this Study, air transportation has been characterized in terms of missions (long-haul, short-haul, cargo, general aviation) and in terms of system elements (vehicles, air traffic control system, airports, complementary ground transportation). Subsequent sections of this report will discuss each of the missions and elements individually. To permit an examination of some of the interactions between missions and to identify the major impacts from these interactions, this section will consider all missions and elements together in the context of a national civil aviation system.

Another objective is to indicate the potential and characteristics of a 1985 civil aviation system that would meet the air transportation needs of the public. To assist in the identification of possible changes required for the 1985 system, it has been necessary to examine the current system and its status (and problems). This has helped to identify those areas that require technical advances.

There is another reason for examining all the missions and elements together. In the past, the major components of civil aviation have in many cases tended to develop independently and somewhat out of phase. The normal pattern has been for air vehicles to lead, with the remaining parts of the system responding to the demand placed on them by new vehicles. The remarkable success and efficiency of modern aircraft have placed other parts of the civil aviation system under considerable stress and often in a position of having to catch up. This is reflected in the current limitation on airport capacity at most major terminals. There is thus a well-recognized need to give increased advance attention to the complete system – especially to the impact on the system of the introduction of new air transport services.

A demand-center concept was used for aggregating the requirements and characteristics of the future air transport system. The demand centers, patterned after hub definitions used by FAA, were used for integration, since the demand centers (which contain the airport(s)) are the points at which all four system elements (air vehicles, air traffic control system, airports, and complementary ground transportation) and the missions come together. In evaluating the demand centers, it was necessary to consider urban centers of varying size, to project future traffic in the various parts of civil aviation serving those centers, to postulate various airports or combinations of airports necessary to accommodate that traffic, and to examine the requirements placed on all components of the civil aviation system.

SUMMARY

Air transport has become the dominant mode of intercity common-carrier passenger travel. This has come about in large part as a result of continual application of technological advances, which have made possible better service to the users at lower prices.

The application of these technical advances and the economies accompanying the use of more, bigger, and better air vehicles in an expanding market have provided a reasonable formula for growth. However, they have also led to congestion, imbalance in the economics of the different air transport sectors, and unfavorable environmental impact. If not resolved, these problems will place serious constraints on the ability of the air transport system to satisfy the potential demand for passenger and cargo services in the future.

The potential demand for air transportation in 1985 is shown in Figure 2.1. The total number of passengers enplaned by U.S. scheduled airlines is expected to grow from 154.4 million in 1969 (ref. 1) to a potential 800 million in 1985. This represents a growth in passenger-miles from 120 billion in 1969 to approximately 700 billion in 1985. In addition, the number of passengers carried by general aviation aircraft is expected to increase to 390 million annually from about 215 million in 1969 (ref. 2). Air cargo traffic is forecast to grow even faster than passenger

service. By 1985, the U.S. airlines are expected to move over 34 million tons annually, nearly 12 times the amount carried in 1969.

This potential level of demand cannot be handled with the existing air system. Larger aircraft and incremental improvements in airports and the air traffic system can service only a portion of the new requirements. Additional facilities will be needed. One possible solution would be to add a large number of conventional takeoff and landing (CTOL) airports throughout the United States. Such airports, however, require extensive amounts of land. It is doubtful that the required number of new CTOL facilities could be established to provide the capacity (and service) to satisfy the potential demand. An alternative solution is to attempt to serve a portion of the total demand (e.g., the short-haul market) in a different fashion – for example, through new short takeoff and landing/vertical takeoff and landing (STOL/VTOL) systems.

Such systems would unload CTOL facilities by providing smaller, less expensive facilities closer to the origins and destinations of short-haul customers. They would also provide short-haul travelers and shippers with better service, while relieving congestion at major CTOL facilities.

An alternative solution for serving the short-haul market is the use of high-speed ground transportation such as rail on existing rights-of-way or high-speed rail or tracked air-cushion vehicles on new rights-of-way. As pointed out in the "Commercial Passenger Service" section of this report, an efficient high-speed ground system is attractive in a region such as the Northeast Corridor where heavy demand centers are located along a "spine." This region has an existing rail right-of-way. Even in the Northeast Corridor, however, it would be impractical to provide fixed right-of-way ground links to all of the areas desiring short-haul service. Other regions of the country, where demand for short-haul travel will be increasing, do not all have the fixed rights-of-way that would allow economic implementation of high-speed ground systems.

On the other hand, air transport systems have an inherent flexibility of route, and can be used throughout the country wherever demand is sufficient to warrant air service. Additionally, analyses discussed in the "Commercial Passenger Service" section show that in regions such as the Northeast Corridor, the future level of demand for short-haul travel will be so great that use of both advanced high-speed rail and STOL/VTOL systems may provide the best solution to meeting the demand.

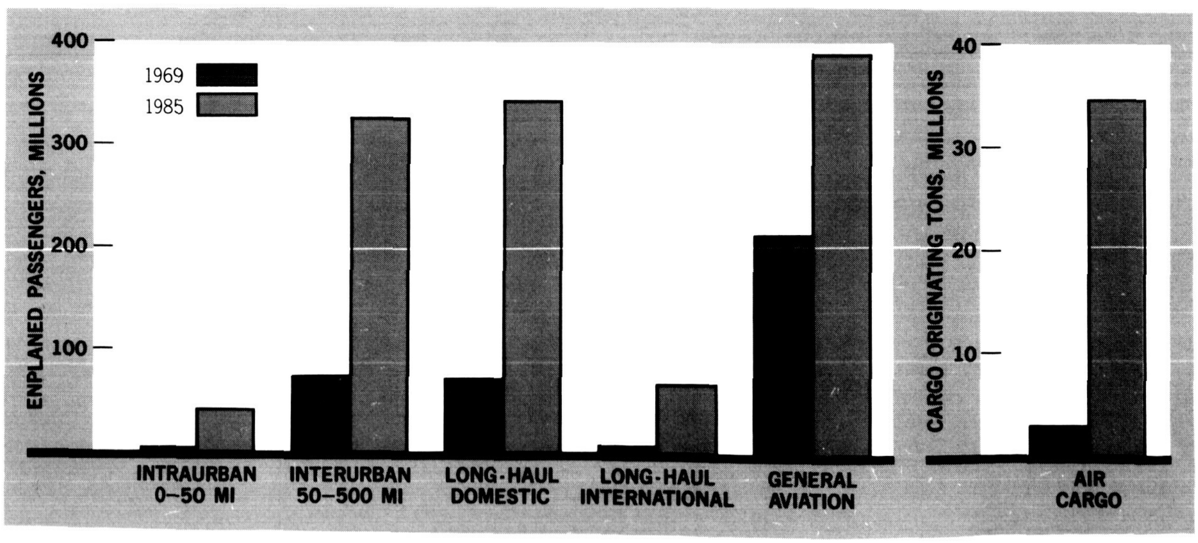
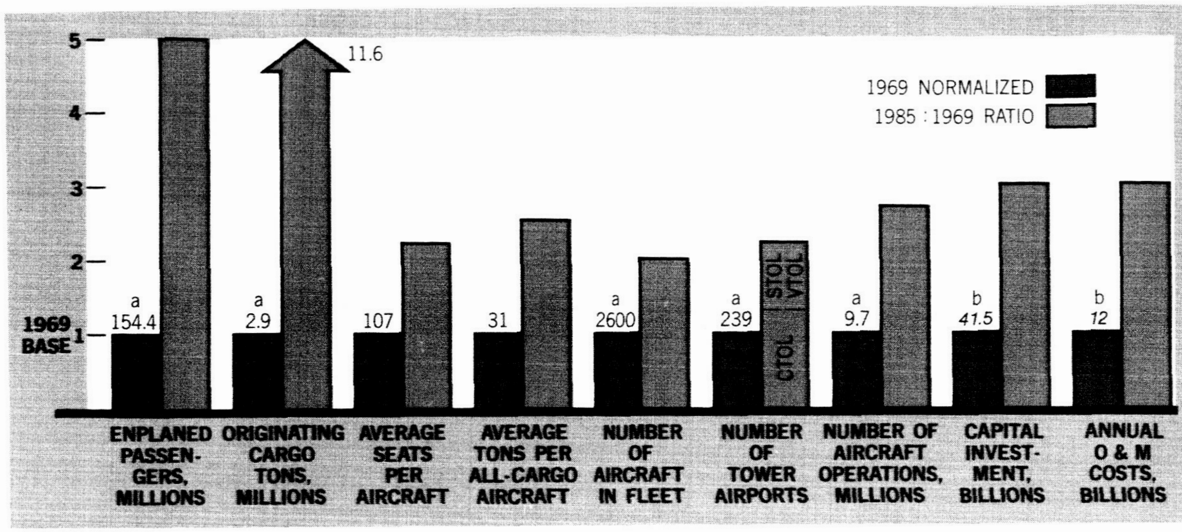


Figure 2.1. 1969 actual and 1985 potential demand, enplaned passengers, originating cargo. *Source: Based on refs. 1, 2, 3.*



[a]*Contiguous 48 states only.* [b]*Total for air vehicles, airports, and airways.*

Figure 2.2. Potential 1985 air carrier system. *Source: Based on refs. 1, 3-6.*

In the interest of a balanced total transport system, it is felt that high-speed ground systems should be developed and should be used where economically feasible. In the future, demand levels and desired origins and destinations will be such that short-haul air service will continue to be required. As shown in the subsequent analyses, STOL/VTOL systems have the potential for providing the best service for the high-density short-haul portion of the air transport system.

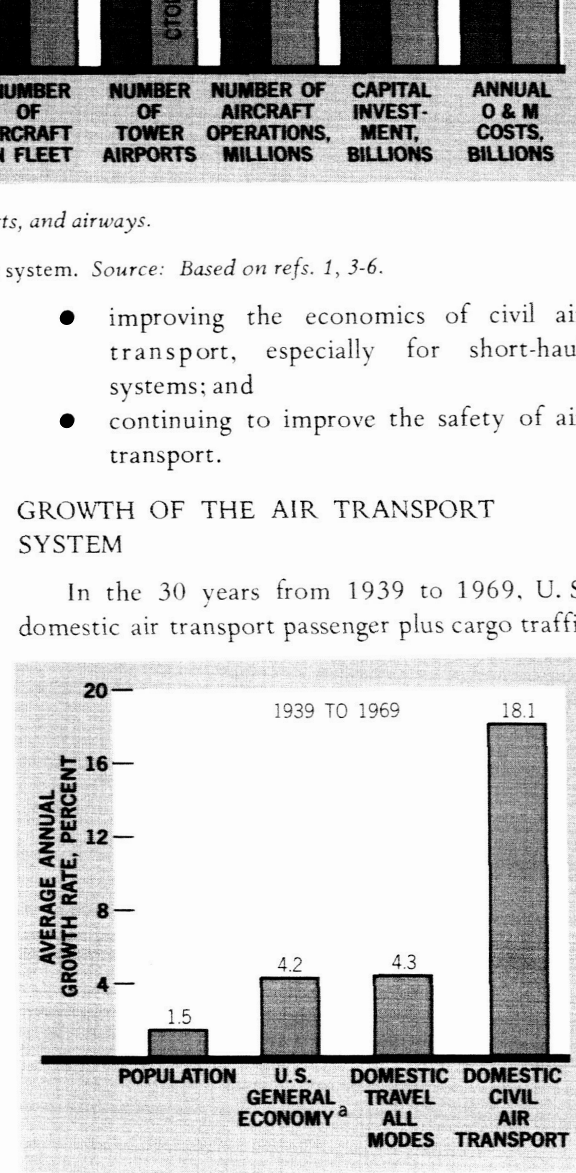
The air transport system for 1985 is envisioned as an integration of multiple systems, tailored to satisfy specific requirements for air service. Based on such a philosophy and the potential demand, the scope and characteristics of the air carrier portion of air transportation for 1985 could be as shown in Figure 2.2. (General aviation is covered separately at the end of this section.)

The potential future air transport system of Figure 2.2 is possible only if significant advances are achieved through R&D aimed at:

- reducing environmental effects to acceptable levels;
- improving system capacity and service, to reduce the door-to-door time for passengers and cargo;
- improving the economics of civil air transport, especially for short-haul systems; and
- continuing to improve the safety of air transport.

GROWTH OF THE AIR TRANSPORT SYSTEM

In the 30 years from 1939 to 1969, U. S. domestic air transport passenger plus cargo traffic



[a]*GNP in constant dollars.*

Figure 2.3. Comparative growth rates, 1939-1969. *Source: Ref. 7.*

(overall common-carrier plus private ton-miles) expanded four times faster than all U. S. domestic transport modes combined, four times faster than the U. S. general economy as a whole, and 12 times faster than the U. S. population (Fig. 2.3).

Air Transport in the Total Domestic Intercity Travel Market

The automobile has dominated the total domestic intercity travel market for many years. It reached a peak in 1961, with 90.2% of the total market. Since then, the auto share of the market declined slowly but steadily, until in 1969 its share (86.5%) had fallen to slightly below its level 30 years earlier (88.6%). During the same 30 years, total air domestic passenger-miles (including both common-carrier and private) climbed from a 0.3% share of the total market in 1939 to 9.8% in 1969. By 1969, bus accounted for only 2.3%, rail 1.1%, and water 0.4% of the total passenger-miles; in 1939, rail constituted 7.6%, bus 3.1%, and water 0.5% of the total passenger-miles. Air transport, then, is the only mode that has captured an increased share of the total domestic travel market in the last 30 years (ref. 7).

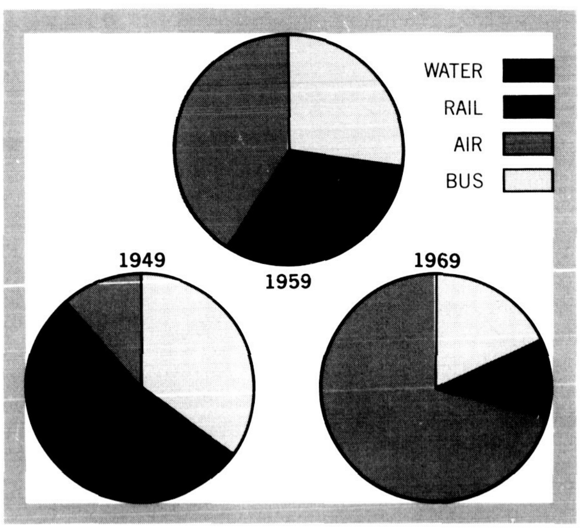


Figure 2.4. Modal split (in percent) of common-carrier domestic intercity passenger-miles, 1949, 1959, and 1969. *Source: Based on ref. 7.*

Air Transport in the Common-Carrier Intercity Travel Market

In the common-carrier intercity travel market, air transportation has been the dominant and fastest growing mode during the last decade or two. In the domestic area, air has been the leader since 1958. The domestic trend is illustrated in Figure 2.4. In the international area, air has been the leader since 1950. Air transport in 1969 accounted for 70.8% of the total domestic intercity common-carrier passenger-miles. In 1969, more than 98% of the U. S. flag-carried passengers between the United States and the rest of the world traveled by air; less than 2% by sea.

Air Cargo

In contrast to its achievements in the passenger sector, air transport still accounts for just a small fraction of the total U. S. domestic intercity cargo traffic (the term "cargo" includes freight, express, and mail). Even today, air transportation provides only 0.17% of the total domestic intercity cargo ton-miles carried by all modes, and only about 1.3% of the total domestic intercity cargo revenues. Air cargo is relatively more important internationally, accounting for about 13% of the U. S.-flag air-plus-sea cargo revenues but probably only about 1% of the total U. S.-flag cargo ton-miles (ref. 7). Air cargo, however, is now experiencing the rapid growth that was enjoyed by the railroads and motor carriers in earlier years. This has come about even though very little emphasis has been placed on cargo systems development. Increased emphasis on this sector of air transport along with recognition of the advantages of cargo movement by air will result in continued significant growth.

General Aviation

The growth of the general aviation sector of civil aviation is reflected in the increase in the number of aircraft and airports of record for a 11-year period, as shown in Table 2.1. Thus, the private use of aircraft has grown along with commercial acceptance and utilization.

TABLE 2.1. GENERAL AVIATION GROWTH

YEAR[a]	TOTAL AIRCRAFT	AIRPORTS OF RECORD
1959	67,839	6,018
1963	84,121	8,084
1967	104,706	9,673
1969	124,237	10,470
1970	130,806	–

[a]*As of Jan. 31*
Source: Ref. 6

STATUS OF THE AIR TRANSPORT SYSTEM

The growth of the total system and its public acceptance would not have come about unless air transportation was providing significant benefits to the public – to the user, the manufacturer, the operator, and the national economy. Coupled with the growth of air transportation have come problems – some that are already affecting the ability of civil aviation to satisfy the potential demand for air transport in the future.

Change has usually come from the air vehicles, with the rest of the system responding to demands imposed by the new aircraft. For example, as the number, size, and productivity of air vehicles increased, airports generally responded with "catch-up" expansions rather than make the large capital outlays needed for new airports. There were also major institutional problems associated with developing new airports. Congestion and delay were the results. Passengers and cargo were affected during surface movement to, from, and within the airports while aircraft were affected at the airport and in the airspace around the airports.

Such congestion and delays detract from the basic advantage of air transport – speed. While the average flight time of aircraft over a given distance has remained about constant since 1960, the average door-to-door elapsed time between some major cities has actually increased.

In addition, even though roughly half of all domestic air passenger movements are for trips of less than 500 miles, very few operators have been able to operate profitably at reasonable rates with existing types of equipment over these short-haul distances. Short-haul operations face the same congestion and delays encountered by long-haul operations so that utilization of aircraft is poor, and thus uneconomical.

One of the most serious problems in all air transportation is the increasingly popular idea that an airport is a poor neighbor. Noise and pollution in the vicinity of airports have caused public alarm, objections to current operations, and resistance to expansion of the system.

Considering the problems already confronting air transport with today's level of demand, it is obvious that vigorous efforts will be required to relieve these problems if the potential of air transport to meet future demand is to be realized.

FUTURE DEMAND FOR CIVIL AIR TRANSPORTATION

By 1985, a dramatic increase in demand is expected in all segments of civil aviation. It is not likely that the market for future air travel will include the entire U. S. population, since available data indicate that as recently as 1967, almost half (45%) the total population had not made even one intercity trip by any mode in the preceding 12 months. On the other hand, the 55% (108 million persons) of the total U. S. population that took one or more domestic or international trips in 1967 (a total of 361 million round trips) constitutes a substantial potential market for air travel. However, 88% of the trips made were by auto, and auto must be expected to continue to be the most popular form of travel – particularly since three out of four auto trips involve two or more passengers, resulting in significantly lower per-person costs.

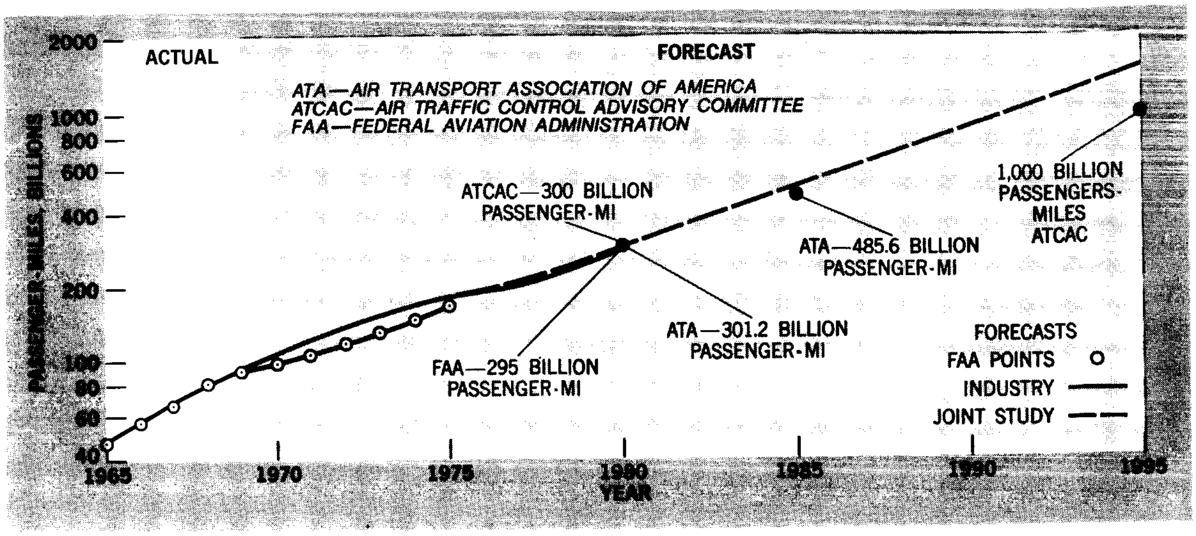


Figure 2.5. U.S. domestic passenger-mile past and forecast growth. *Source: FAA data, ref. 8; ATCAC data, ref. 9.*

Passenger Miles

To put the forecast passenger demand levels in perspective, a review was made of the latest industry and Government forecasts. A comparison of these forecasts for domestic passenger service is shown in Figure 2.5. The passenger demand forecast of the Joint Study was based on FAA data for fiscal years 1970 through 1981 (ref. 8). This forecast shows an average annual growth rate in passenger-miles of 12% per year. The Joint Study assumed that this growth would continue through 1995. This relatively unconstrained growth can be achieved only by providing increased capacity and service, improved operating economics, minimal impact on the environment, and a high degree of safety.

Table 2.2 presents summaries of various forecasts of international traffic through 1985. Due to variations in the definition of base-year traffic (1969), the forecasts are not directly comparable but give some indication of the magnitude of future demand. A note of clarification is appropriate for the Joint Study demand level shown. The values reflect only passenger-miles generated by U. S. common-carrier flights leaving from and

TABLE 2.2. INTERNATIONAL REVENUE PASSENGER-MILES, BILLIONS (U.S. SCHEDULED SERVICE ONLY)

FISCAL YEAR	FAA	ATCAC[a]	DOUGLAS	BOEING	JOINT STUDY[b]
1969	27.9	–	30.6	29.5	9.1
1975	59.5	–	67.1	70.6	–
1980	107.5	150.0	115.7	115.3	–
1985	–	420.0	186.6	–	130.0

[a]*ATCAC forecast includes nonscheduled operations.*

[b]*The Joint Study forecast is only for flights departing from or returning to the United States.*

returning to the United States and do not consider flights by U. S. carriers between foreign countries. (This approach was taken to determine the impact of these activities on facilities within the United States.)

Enplaned Passengers

Another measure of demand is the "enplaned passenger." Figure 2.1 showed the distribution of enplaned passengers by type of operation for both air carriers and general aviation. It is estimated that there will be 733 million domestic passengers enplaned by airlines in the United States in 1985, a five-fold increase over the 149

million passengers in 1969. The greatest percentage growth in passenger enplanements will be at the extremes of the distance spectrum. An estimated 39 million passengers will be enplaned on trips of less than 50 miles in 1985, compared with approximately 1.7 million enplanements in 1969. This growth can be expected to occur if more efficient air service can be introduced in the intra-urban environment, primarily providing connecting service for long-haul air flights but providing some normal, daily transportation as well.

The growth in international enplanements from 5.6 million in 1969 to approximately 65 million in 1985 will result from many of the same factors that affect the other segments of the air transport business. Among these factors are continued vehicle improvement in the form of speed, comfort, reliability, and unit operating costs; a shift in the population mix to a younger, more educated population; increased per capita disposable income; longer vacations; and expanded international trade.

AIR TRANSPORT CONCEPTS AND POTENTIAL FOR 1985

Demand Center Concept

The impact of the predicted demand is difficult to envision at the aggregate national level. It is more illuminating to examine typical metropolitan areas utilizing aviation services (demand centers). Potential air system requirements and characteristics were arrived at by considering different

TABLE 2.3. POTENTIAL 1985 DEMAND BY DEMAND CENTER[a]

	1969[b]						1985					
	SUPER	LARGE	MEDIUM	SMALL	NON	TOTAL	SUPER	LARGE	MEDIUM	SMALL	NON	TOTAL
NUMBER OF DEMAND AREAS	7	14	37	93	80	231	9	12	40	85	146	292
PERCENT OF NATIONAL DEMAND[c]	6	1.7	0.5	0.1	0.03		5.3	1.9	0.58	0.055	0.015	
AIR CARRIER[d]												
ENPLANED PASSENGERS, MILLIONS	9.5	2.6	0.8	0.21	0.05	154.4	45.1	14.8	4.2	0.4	0.11	798
PASSENGER-MILES, BILLIONS	8.55	2.13	0.66	0.056	0.012	120.0	43.2	12.7	3.35	0.1	0.03	685
CARGO[d]												
ORIGINATING TONS, THOUSANDS	223	59.5	12.7	3.5		3,140	2,800	535	73	2	–	34,700
TON-MILES, MILLIONS	431.2	120.5	21.4	5.5		5,880	5,470	920	65	1.3		62,400
GENERAL AVIATION BASED AIRCRAFT	1,534	1,416	388	175	[e] 64,254	[f] 124,237	4,450	1,880	870	550	[e] 143,000	287,000

[a] *All values in matrix except totals are per-hub averages.*

[b] *Distribution of data by demand area is based on statistical data in refs. 7 and 12.*

[c] *Based on carrier enplaned passengers.*

[d] *Domestic and international; contiguous 48 states only.*

[e] *These figures are the total for the remainder of the U.S. which does not fall into the hub classifications of super, large, medium, and small. This is required for general aviation examination since a large portion of general aviation aircraft activities occur outside the hubs (unlike air carrier, where almost all operations occur within the hubs).*

[f] *As of January 1.*

types of demand centers and the numbers of each that will be required throughout the United States. The demand centers, also referred to as hubs (ref. 10), were used for integrating and evaluating the air system because these centers are the only places where all four systems elements (air vehicles, air traffic control system, airports, and complementary ground transportation) and missions (short-haul, long-haul, etc.) come together. Each center is classified by its percentage of the total air carrier enplaned passengers. In this study, the classifications in terms of enplanements were: super – 3% and over; large –1.00% to 2.99%;

TABLE 2.4. POTENTIAL 1985 SUPER DEMAND CENTER ACTIVITIES

AIR CARRIER	1969	1985
PASSENGER		
ENPLANED PASSENGERS, MILLIONS		
DOMESTIC SHORT-HAUL (0-50 MI.)	0.15	2.7
DOMESTIC SHORT-HAUL (50-500 MI.)	3.5	15.5
DOMESTIC CHARTER	(a)	0.7
TAXI	0.12	(b)
DOMESTIC LONG-HAUL	5.1	19.7
TOTAL DOMESTIC	8.9	38.6
INTERNATIONAL	0.6	6.5
TOTAL DOMESTIC AND INTERNATIONAL	9.5	45.1
PASSENGER-MILES, BILLIONS		
DOMESTIC SHORT-HAUL	1.03	5.0
DOMESTIC LONG-HAUL	6.35	23.8
DOMESTIC CHARTER		1.4
TOTAL DOMESTIC	7.38	30.2
INTERNATIONAL	1.17	13.0
TOTAL DOMESTIC AND INTERNATIONAL	8.55	43.2
CARGO		
ORIGINATING TONS, THOUSANDS		
DOMESTIC FREIGHT	96	1,860
DOMESTIC MAIL	67	100
DOMESTIC EXPRESS	9	40
TOTAL DOMESTIC	172	2,000
INTERNATIONAL	51	800
TOTAL DOMESTIC AND INTERNATIONAL	223	2,800
TON-MILES, MILLIONS		
DOMESTIC SHORT-HAUL	21.7	450
DOMESTIC LONG-HAUL	286.0	2,100
TOTAL DOMESTIC	307.7	2,550
INTERNATIONAL	123.5	2,920
TOTAL DOMESTIC AND INTERNATIONAL	431.2	5,470
GENERAL AVIATION		
FIXED-BASED AIRCRAFT	1,534	4,450
ITINERANT OPERATIONS, MILLIONS	0.51	2.64
LOCAL OPERATIONS, MILLIONS	0.45	2.13
TOTAL OPERATIONS, MILLIONS	0.96	4.77

[a] *Included in domestic short- and long-haul figures.*

[b] *Included in General Aviation. Source: Refs. 1, 3, 4, 6, 11-13.*

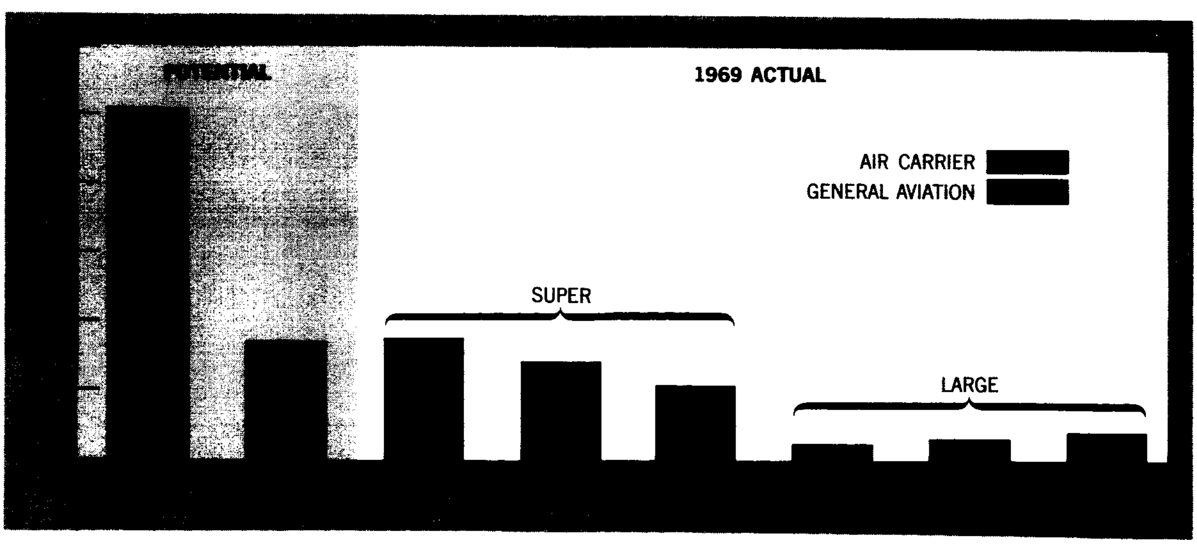
medium – 0.25% to 0.99%; small – 0.05% to 0.24%; nonhub – less than 0.05%.

Table 2.3 is a summary of the demand by demand center classification for 1969 and the potential demand for 1985. The levels shown were arrived at by analysis of past trends in the distribution of demand by hub category. It can be seen that a growth in the total number of demand centers from 231 to a potential 292 is projected to occur between 1969 and 1985. The data in Table 2.3 are for typical demand centers. Actual demand centers will vary in terms of levels of demand, distribution between missions, etc., but the "average" demand centers should have the potential demand shown.

Demand was further divided by mission: short-haul intraurban (0-50 miles, primarily air taxi and feeder service); short-haul interurban (50-500 miles); long-haul domestic (greater than 500 miles within the continental United States); long-haul international (all travel to and from the continental United States); and cargo (all domestic and international goods). Table 2.4 shows a detailed breakout for a typical super demand center. Comparable data were developed for each of the other classes of demand center.

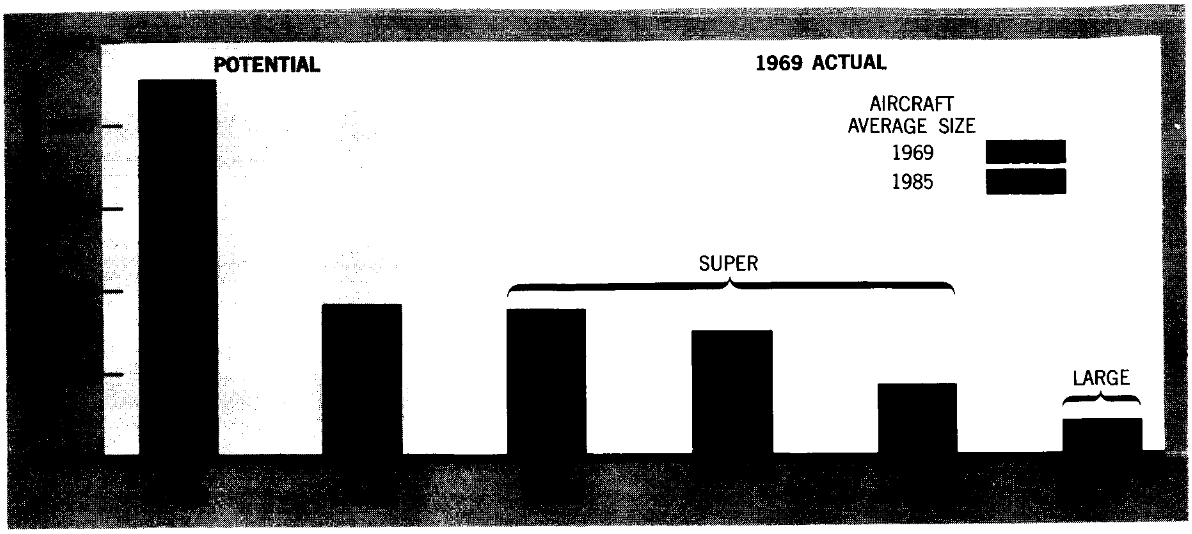
Figure 2.6 shows the potential number of enplaned passengers for average super and large demand centers in 1985. For comparison, this same measure of demand (for 1969) is shown for three current super hubs and three large hubs (the 21 large hubs defined in ref. 14 include the super and large demand centers as defined for the Joint Study). It is projected that by 1985 at least 9 demand centers will be categorized as "super," and 12 as "large." The average 1985 large demand center will exceed a current super hub, and the 9 super demand centers will far outstrip any current demand area. Although not shown in the figure, the average medium demand center (of which there will be 40) will have a greater passenger demand than the current large hubs (Table 2.3).

One way to increase the capacity of the air system to serve such a potential demand is to continue the current trend of introducing larger capacity aircraft. Figure 2.7 shows the alleviation of problems with certain elements of the air system, especially airports (airside) and the air traffic system, which will occur if this trend is continued. Shown in this figure are the number of air



[a]*Includes Newark.*

Figure 2.6. Enplaned passengers. *Source: Based on refs. 3, 14.*



[a]Includes Newark.

Figure 2.7. Air carrier aircraft operations. *Source: Based on ref. 3.*

carrier operations at the average 1985 super and large demand centers for two different situations: (1) the average passenger aircraft size for all air travel beyond 50 miles is the same as in 1970 (approximately 107 seats per aircraft); and (2) the average size is approximately 240 seats per aircraft (based on a detailed analysis of 1985 potential demand by demand center and the mix of vehicles best suited to satisfy this demand). Comparable increases in all-cargo aircraft sizes in 1985 are also included in calculating the number of operations.

As may be seen from Figure 2.7, with the 1970 average-size aircraft, the number of air carrier operations at an average super demand center in 1985 would be more than two and one-half times the number carried out at the New York hub in 1969 and almost six times the number at the Los Angeles hub in 1969. (It must be kept in mind that there could be 9 such super demand centers in 1985.) Using the projected 1985 average aircraft size reduces the number to about one and one-half times the number of operations at the New York hub in 1969.

The existing civil aviation system structure could not accommodate the projected potential level of commercial air activities. This projected level does not include the added impact of general aviation activities on the total system. Larger aircraft and incremental improvements in airports and air traffic control will provide some relief, but will fail to provide the capacity and service required. The number of people to be served (see Fig. 2.6) is still a critical factor. Several of the Nation's airports are currently at peak-hour saturation, not only in terms of the number of aircraft they can accept but in terms of overloads on terminal-building facilities, automobile parking, baggage-handling, and airport access/egress.

Additional facilities will be necessary. One solution might be to add new CTOL airports throughout the United States and continue with the present system. New CTOL airports, however, require extensive amounts of land, and opposition to new airports is great. Many of the areas most in need of new facilities will not accept the development of entirely new land-consuming CTOL airports. An alternative solution is to serve the short-haul portion of the total demand through the use of STOL/VTOL systems. Besides requiring much less land, it is possible that a new "good neighbor" image can be established for a "new" system concept, if R&D results show – in actual demonstrations – that the system is "quiet" and "safe."

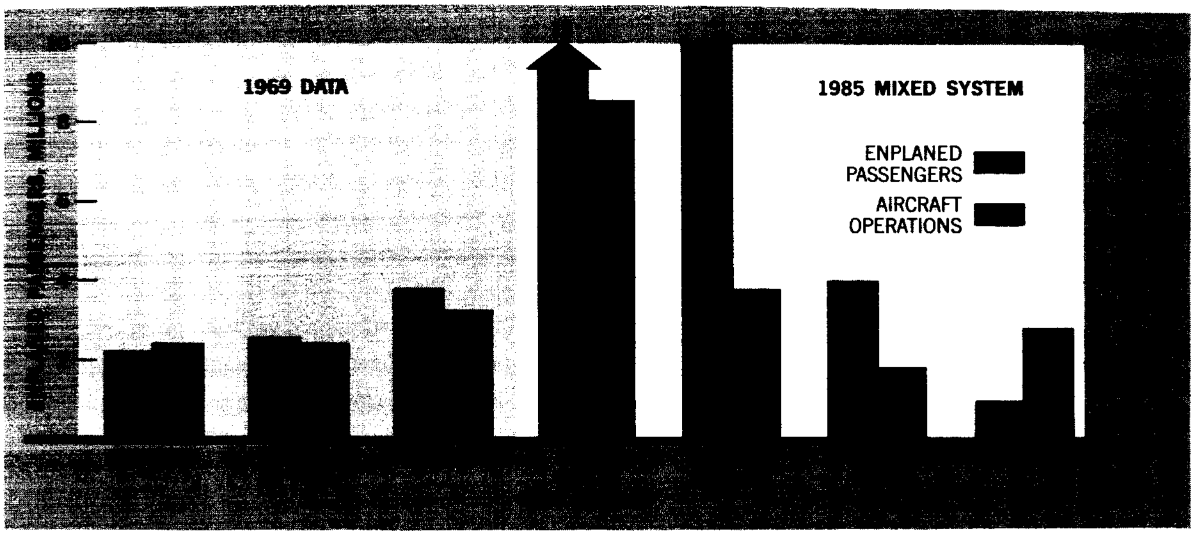


Figure 2.8. Large demand center scheduled air carrier activities. *Source: Based on ref. 3.*

Figure 2.8 shows how the demand might be distributed at a large demand center in the future if a system concept were developed and implemented that contained CTOL, STOL, and VTOL facilities and systems, each providing service to that segment of air travel to which it is best suited. Also shown is the comparable level of activity that would occur at a single CTOL airport if the entire potential demand were to be funneled through one facility. This level compares to the 1969 levels at the three hubs shown in the figure (typical of today's large hubs). The mixed concept reduces the number of enplanements at the CTOL facility by a third and reduces the number of operations by more than half. Equally important, locating the facilities closer to the demand provides the short-haul traveler with better service.

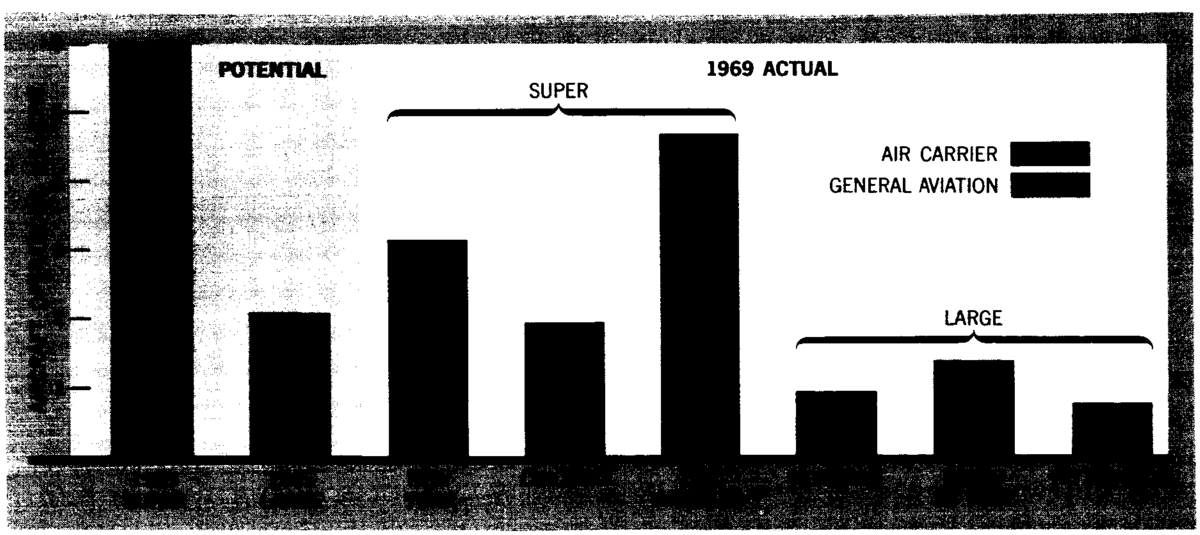


Figure 2.9. Aircraft operations. *Source: Based on refs. 3, 10, 14.*

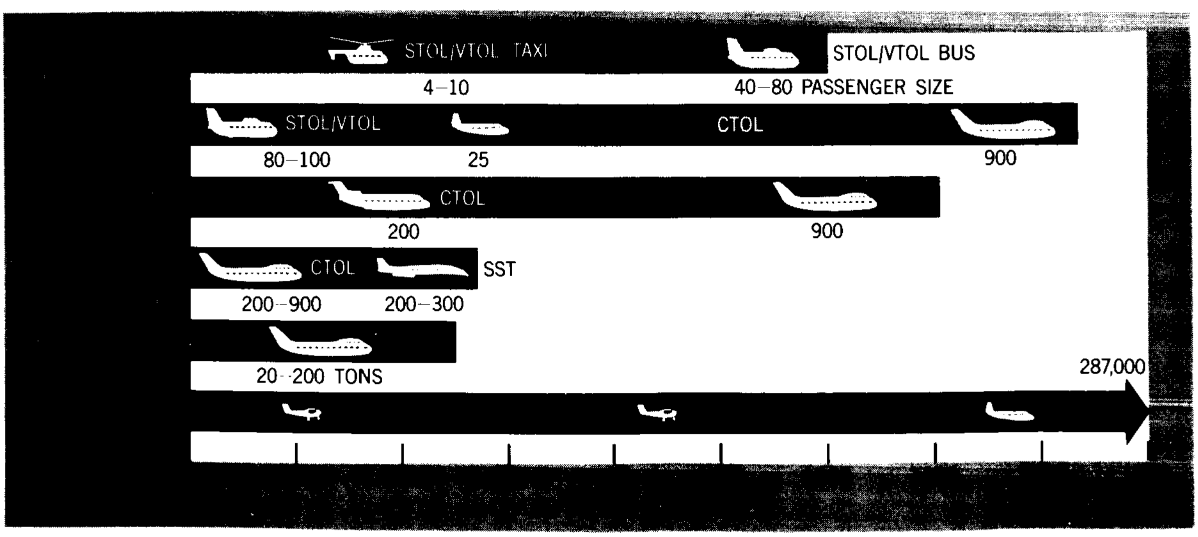
The mixed concept provides more relief (percentage reduction) to the CTOL airport in terms of aircraft operations than in terms of enplaned passengers, and aircraft operations is the priority area for relief when the impact of general aviation is considered. Although the number of passengers enplaned by general aviation is small compared to air carrier passengers (Fig. 2.6), the number of general aviation operations is extremely large, as shown in Figure 2.9.

General aviation operations at a large demand center in 1985 could be four times the number of air carrier operations. The majority of these operations should be distributed to separate general aviation facilities within the demand center, but a large number of these (especially nonscheduled air taxi operations and business jets) will be handled by the CTOL facility. At the super demand centers of 1985 there will be an even greater requirement for dispersal of portions of air service. Even with separate STOL/VTOL facilities, the potential level of demand is such that additional CTOL facilities will be required at some of the future super demand centers.

The Potential 1985 Air Transport System

The previous discussion reflects a philosophy for a potential air transport system that would meet the demand for services in 1985. Based on such a philosophy, and the demand shown in Table 2.3, the scope and characteristics of an air transport system for 1985 were defined. Such a system will necessarily reflect many new characteristics in the primary elements (air vehicles, airports, air traffic system, complementary ground transportation) resulting from application of technological advances and developments.

Air Vehicles. To service the potential demand efficiently, the air carrier fleet (see Fig. 2.10) will have passenger-seat capacities from 4 (VTOL taxi) to 900 (CTOL for high-density routes). The supersonic transport will serve transoceanic routes in the international market. New CTOL, STOL, and VTOL aircraft will provide service for the Nation's short-haul requirements. General aviation aircraft will grow in number to about 287,000 by 1985.



Note: Vehicle seating capacities may differ slightly from seating capacities discussed in other sections of this report. Nominal values were selected for purposes of this section.

Figure 2.10. Potential 1985 U.S. air carrier and general aviation fleet.

The aircraft in the potential 1985 fleet will provide convenient, economical service. It should be noted that two major forces acting on aircraft size tend to counteract; the objective of convenience drives toward smaller size to make possible the desired frequency of service, while the economic objective drives toward larger size. There should be more than 35 demand areas having enough traffic to support five daily round trips with a 900-passenger aircraft at an average load factor of 55%. The largest five markets would require more than 20 daily round trips with such a vehicle. At the other end of the spectrum, in the low-density area of the air carrier system, the requirement to provide adequately frequent service for a minimum of four daily round trips will require 25- to 50-passenger aircraft.

The 1985 air carrier fleet will be structured to serve the demand with the largest aircraft that can support reasonable minimum frequencies. Because a large proportion of the markets today enjoys more than the minimum desired service levels, the greatest part of the projected growth can be accomplished by increasing vehicle size; the fleet would only double, whereas passenger traffic can potentially increase to five times its present level.

Airports. In the projected structure for a super demand center in 1985, over 50% of the commercial air operations would be conducted at STOL and VTOLports. CTOLpotts would thus be relieved of a large portion of the short-haul load while access/egress would be improved by V/STOLports located closer to the demand. Under this concept, the CTOLports at a 1985 super demand center would not be much larger than those currently in use. Thus, the improved airport, air traffic, and complementary ground transport systems will not be as strained, and will be better able to provide the capacity, service, and safety required to efficiently satisfy the demand.

The alternative of a single centralized facility (i.e., a "supersize" airport) was also examined. Although certain advantages of economy accrue from minimizing the redundancy of investment and operating costs via centralization, the advantages evaporate rapidly in an operational environment that is very sensitive to frequent periods of near-saturation peaking in both air- and ground-side activity. Moreover, the practicality of establishing new supersize airports is doubtful – except, perhaps, in unique circumstances.

In the super demand areas, several general aviation airports, some with sophisticated landing aids and some "nontower" airports, will serve the general aviation market. The tower airports could also serve as reliever airports for the air carriers.

In about half the large hub demand centers, the volume of CTOL traffic forecast for 1985 can be accommodated effectively by a single airport. The balance will require a second facility. As with all demand centers, the decision in each situation will depend on a combination of the traffic level and the demographic and topographic characteristics of the region. It was estimated that a single V/STOLport would provide the most cost-effective solution for the V/STOL interurban traffic in a large demand center. If the requisite R&D is achieved to demonstrate that V/STOL operations will be quiet and safe, the ability to site such a facility without some of the constraints (size, "image") inherent in CTOL airport location may enable it to be located close to the demand and the intermodal systems.

In summary, the number of airports across the country must increase and provide improved service. STOL and VTOLports, nonexistent today, would bring together passengers and aircraft at points closer to origin and destination, improving the access and egress travel time. Where necessary, CTOLports will have multiple parallel runways to handle peak movements. Spacing between runways will be reduced to minimize land required and reduce airport investment costs. New techniques in ticketing and in passenger-, baggage-, and cargo-handling will upgrade the

quality of service over that offered today. Access and egress planning will improve intermodal transfer of air passengers and cargo.

Air Traffic Control System. The air traffic system postulated for 1985 contemplates accomplishment of the FAA's 10-year plan, which includes the major recommendations of ATCAC (ref. 9). Some of the control functions would be automated; conflict prediction and resolution would be computerized and an automatic digital ground-air-ground data link would pass the instructions to the pilot. Next-generation improvements would include conversion to more automatic control methods, with more of the control performed in the aircraft.

It is expected that there will be automatic altitude reporting and identification for the airlines, and more sophisticated general aviation aircraft to facilitate more efficient handling of traffic in the dense traffic areas around major hubs, with metering and spacing of aircraft approaches to obtain the maximum use of the airport facilities.

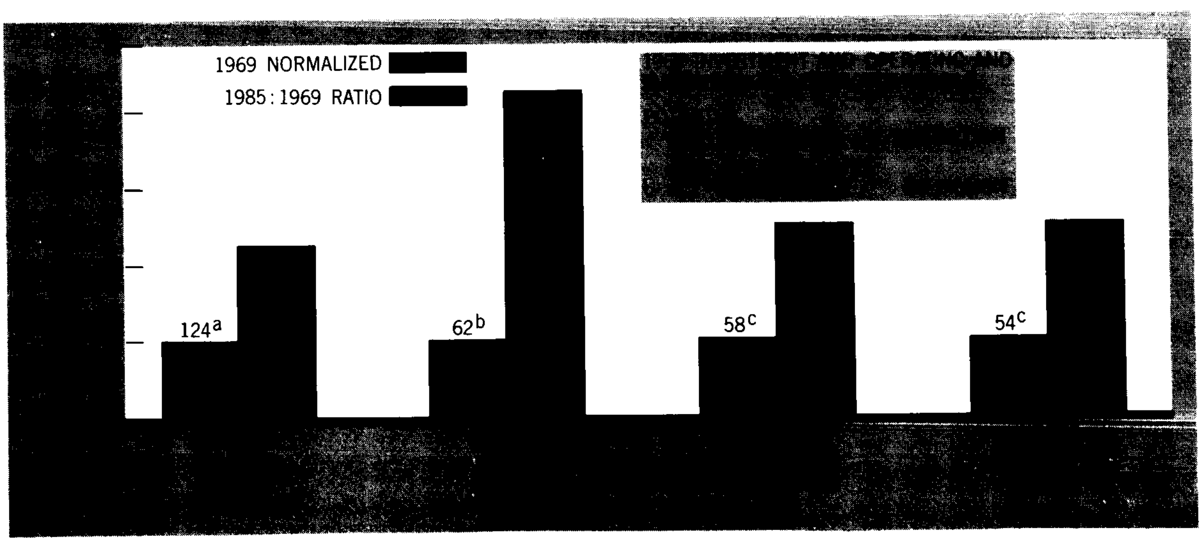
Controlled airspace will extend below the present 18,000 feet, but there will still be extensive uncontrolled space for the general aviation, VFR pleasure flier. Safety in these areas will be enhanced by intermittent positive control.

1985 System Summary

In summary, the 1985 civil air transport system should provide a reliable and responsive quality of service to meet the Nation's demands without loss in safety or efficiency.

The scope of the air carrier portion of such a potential system was indicated in quantitative terms in Figure 2.2. The scope of the general aviation portion is shown in Figure 2.11. The potential levels of investment and annual operating and maintenance costs associated with such a system are also shown in both figures.

The achievement of such an air transport system, with operating and safety characteristics attractive to the user, environmental characteristics acceptable to the public, and economic characteristics that justify and attract the amount of capital required will be possible only if significant advances are made in certain areas of R&D. These areas are discussed in the following sections of the report.



[a]*As of January 1, 1969; based on ref. 7.*

[b]*Contiguous 48 states; based on ref. 6.*

[c]*Based on ref. 2*

Figure 2.11 1985 general aviation potential.

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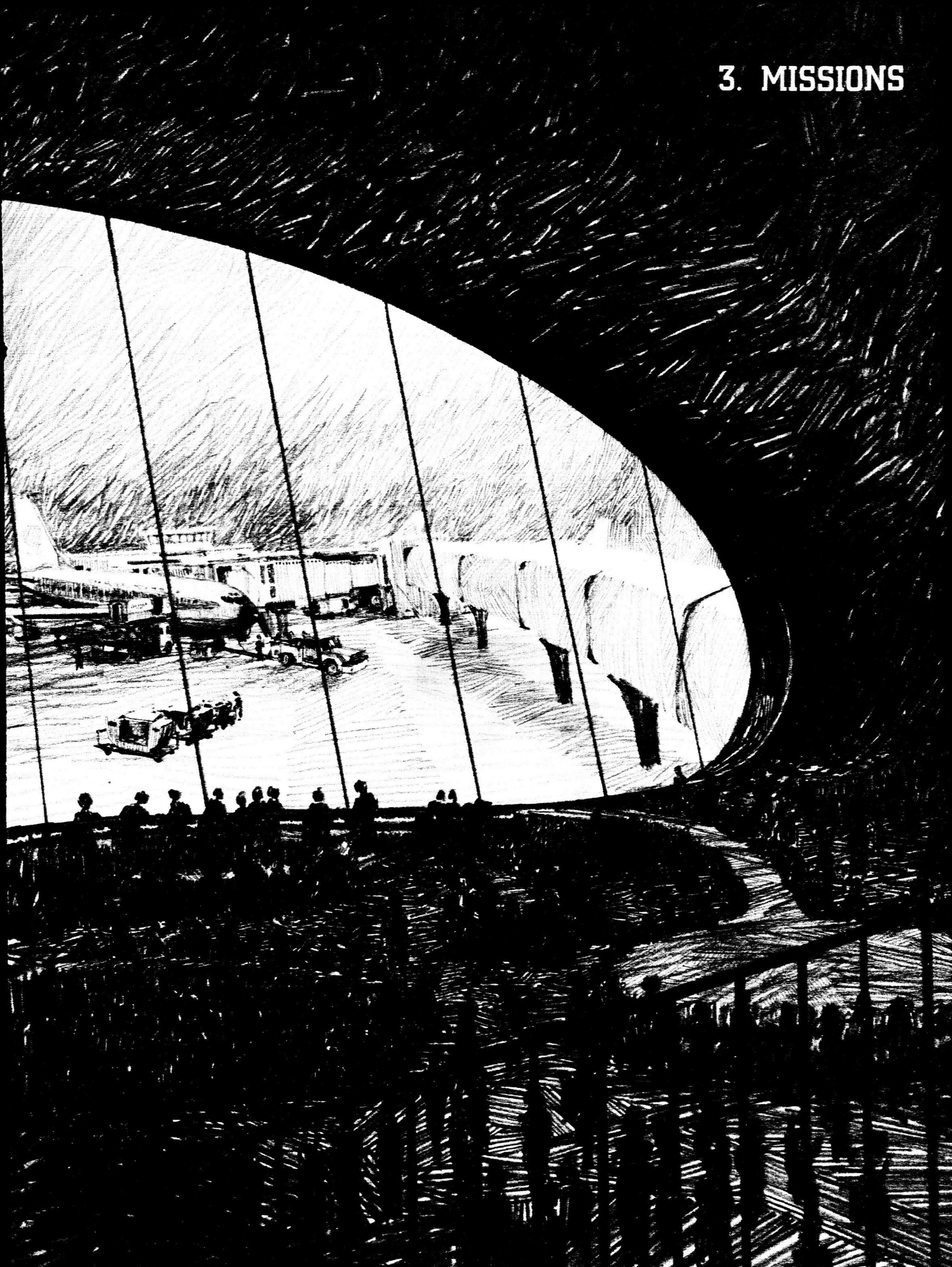
3. MISSIONS



Missions

COMMERCIAL PASSENGER SERVICE

INTRODUCTION

Air transportation has become an accepted part of modern life. Many tend to forget how far it has advanced in a relatively short time. In 44 years, U. S. air transport has expanded from a primitive short-haul domestic operation to a sophisticated system that can transport people and goods to any place in the world in one day or less. Figure 3.1 shows a 110-mile-per-hour Boeing Model 40–B single-engine biplane, photographed in 1929. The pilot sat in an open cockpit, and four passengers and 1,500 pounds of mail were carried in a small enclosed cabin behind the engine; this airplane entered airline service in 1927. In contrast, the total system today includes thousands of safe, high-performance aircraft carrying up to 360 passengers, a worldwide air traffic control system that safely guides aircraft from one city to another, hundreds of airports that handle millions of passengers, and complementary ground transportation systems of varying degrees of sophistication that transport passengers and cargo to and from the airports.

Figure 3.1. Air transport in 1929.

GROWTH OF THE SYSTEM

In 1928, one of the advanced transports of the period – the Boeing Model 80 trimotor – entered airline service (Fig. 3.2). A biplane, it had a range of 460 miles and a cruising speed of 115 miles per hour and carried 12 passengers in a luxurious cabin with hot and cold running water, forced-air ventilation, four rows of leather upholstered seats, and individual reading lamps. Few airports of the time had paved runways, and during rainy weather the landing fields were covered with mud. The airport terminal was usually a room attached to the end of a hangar. Air traffic control and accurate weather data were unavailable, and scheduled passenger flights were at the mercy of the weather and were limited to daytime operations. Despite these limitations, domestic air transportation in the United States grew from 1.3 million passenger-miles in 1926 to 85 million passenger-miles in 1930.

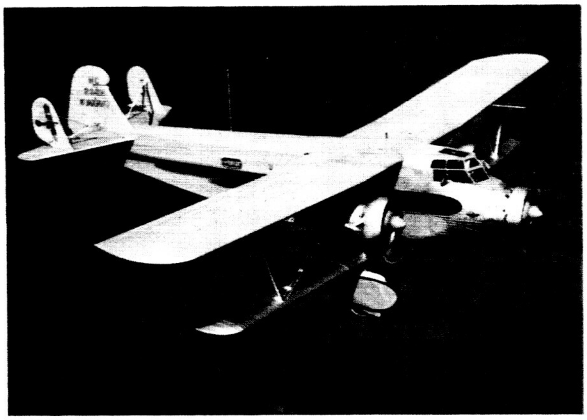


Figure 3.2. The Boeing Model 80 Transport.
(Courtesy of The Boeing Company.)

By 1970, domestic scheduled air service in the U. S. totaled some 104 billion passenger-miles (Fig. 3.3). International U. S.-flag traffic accounted for an additional 28 billion passenger-miles. This growth is expected to continue through 1985.

CHANGING CHARACTER OF THE SYSTEM

The character of the air transportation system has changed over the years (see Figs. 3.4 and

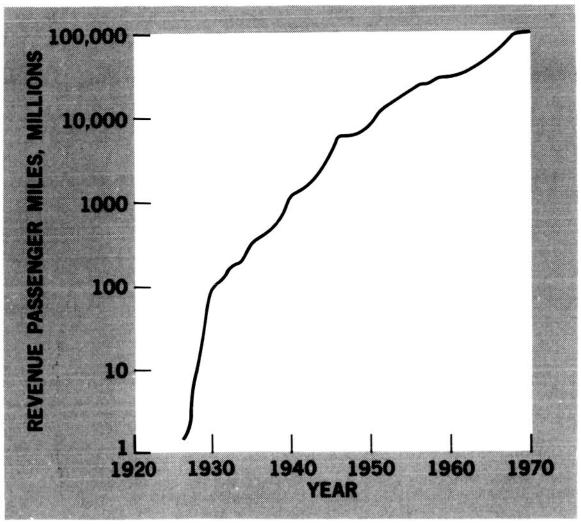


Figure 3.3. Growth of U.S. domestic scheduled revenue passenger-miles: 1926-1969. *Source: Ref. 1.*

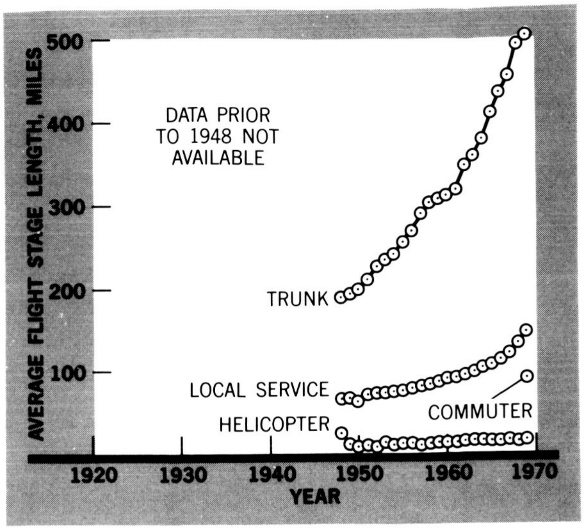


Figure 3.5. U.S. domestic average overall flight stage length in scheduled service. *Source: Ref. 1.*

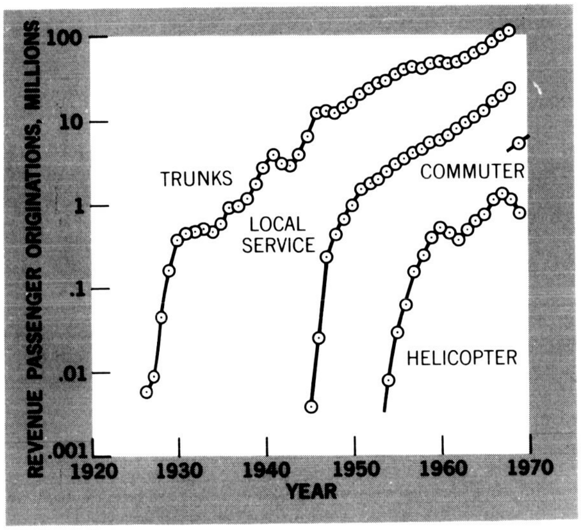


Figure 3.4. U.S. domestic revenue passenger originations. *Source: Ref. 1.*

3.5) as it expanded to provide service to a greater number of cities. In 1938 the Federal Government established the Civil Aeronautics Authority, which awarded routes to the existing air carriers (now known as trunks) and regulated passenger, cargo, and mail rates. In 1945 the local service carriers were established to provide feeder service from outlying areas to larger cities and between communities that were too small to support trunk service. The first helicopter intraurban service was started in 1947 to serve the needs of the Los Angeles metropolitan area. The supplemental air carriers were started in 1948 to provide charter passenger and cargo services, and in 1949 the all-cargo carriers were established to concentrate on scheduled freight service. In 1969, scheduled service was again expanded when the scheduled air taxi operators were renamed "commuter air carriers" and encouraged to provide more frequent passenger, cargo, and mail service in small aircraft (usually under 12,500 lb) for the smaller communities that were no longer being adequately served by the local service airlines and their larger aircraft.

PROBLEMS OF SHORT-HAUL OPERATIONS

Operational problems of the local service airlines, the helicopter airlines, and the commuter airlines arise from the short stage lengths flown, the relatively small number of passengers carried, and the large number of cities served. The intraurban system (helicopter service) is handicapped by its very short stage length and high unit operating costs, resulting in high fares that only a small number of passengers are willing to pay. The main problems of the local service and commuter airlines stem from the fact that they serve a

large number of cities (commuter lines served about 1,200 cities in 1969) relatively close together which, coupled with the relatively few passengers, puts extreme requirements on the aircraft and results in high per-passenger-mile costs, and hence, fares. On the other hand, the trunk lines carry a large number of passengers over relatively long stage lengths. The problems associated with long-haul operations are different from those of short-haul operations. The following discussion, therefore, will consider each class separately.

LONG-HAUL SYSTEMS

The long-haul domestic and international passenger system consists of those air vehicles that customarily carry commercial passengers on stage lengths from 500 to 6,000 miles, and those portions of the airports and the air traffic control system that support such passenger transportation.

Historically the long-haul market has been the backbone of the air transport system. Now, however, a number of problems, unless solved in the near future, will seriously impair the efficiency, safety, and convenience of long-haul air travel. The most pressing problems are noise, terminal congestion, and lack of an operational all-weather takeoff and landing system.

Figure 3.6. The Boeing 747.
(Courtesy of the Port of New York Authority.)

The air transport industry has introduced new, more productive aircraft about every seven years. The latest aircraft to enter service is the Boeing 747, shown in Figure 3.6. The typical mixed-class configuration has about 350–360 seats, but the aircraft can accommodate 490 passengers in an all-economy configuration. To complement the improved aircraft, modern airports are distributed around the world. An air traffic system provides safe passage for aircraft in almost any weather conditions. Much has been accomplished, but it is necessary now to consider what needs to be done to assure that progress continues.

VEHICLES

The most important contributor to the growth of air transportation has been the air vehicle. Each new aircraft has represented an advance in technology which resulted in productivity increases in terms of seat-miles per hour through combinations of aircraft size and speed, usually accomplished by significantly reduced operating costs.

Figure 3.7 shows how improvements in productivity have affected the direct operating costs (DOC) of the aircraft. Over the years, the

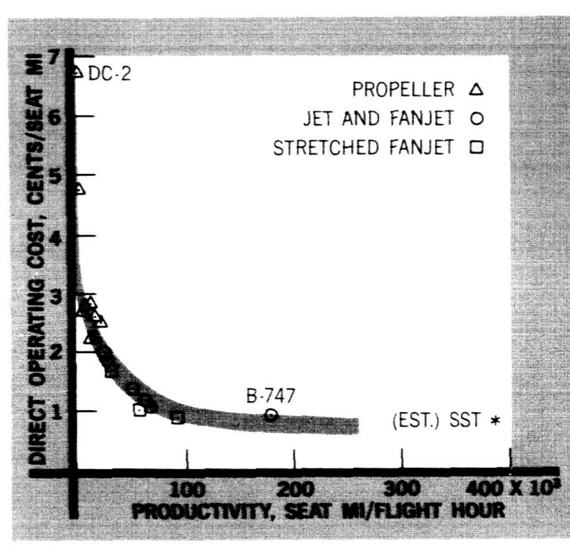


Figure 3.7. Direct operating cost versus productivity.
Source: Ref. 2.

improvements made possible by Government and industry research and development in aerodynamics, structures, materials, and propulsion have resulted in reducing the DOC's per available seat-mile from about 6.7¢ for the DC–2 in 1934 to less than 1¢ for the 747 in 1970. Decreases in operating costs (resulting from increased productivity) have about counterbalanced the rise in general price levels. Although levels of comfort and convenience to the passenger have continued to improve, Figure 3.8 indicates that average yields (adjusted fares, in cents per passenger-mile) have remained about constant over the past 30 years (ref. 1). If the results of R&D had not been applied, aircraft productivity could not have kept pace over the last 30 years and current fares would be much higher. If they had varied with the Consumer Price Index for Transportation (ref. 3), the average adjusted fare for 1969 would have been about 12¢ per seat-mile – about the same level as in 1929 – instead of 5.6¢ (see Fig. 3.8). Assuming that three-quarters of the improvement in DOC (Fig. 3.7) could have been obtained by increases in size alone, the increase in average adjusted fare experienced without the increased speed would have been 1.6¢ per revenue passenger-mile. (Increases in size stem in part from R&D.) U. S. trunk airlines carried about

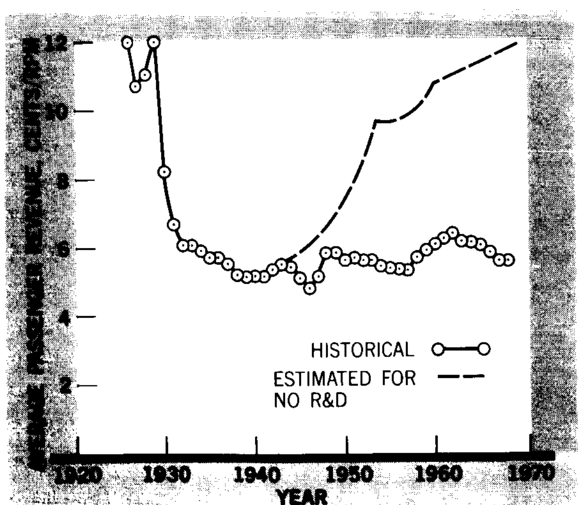
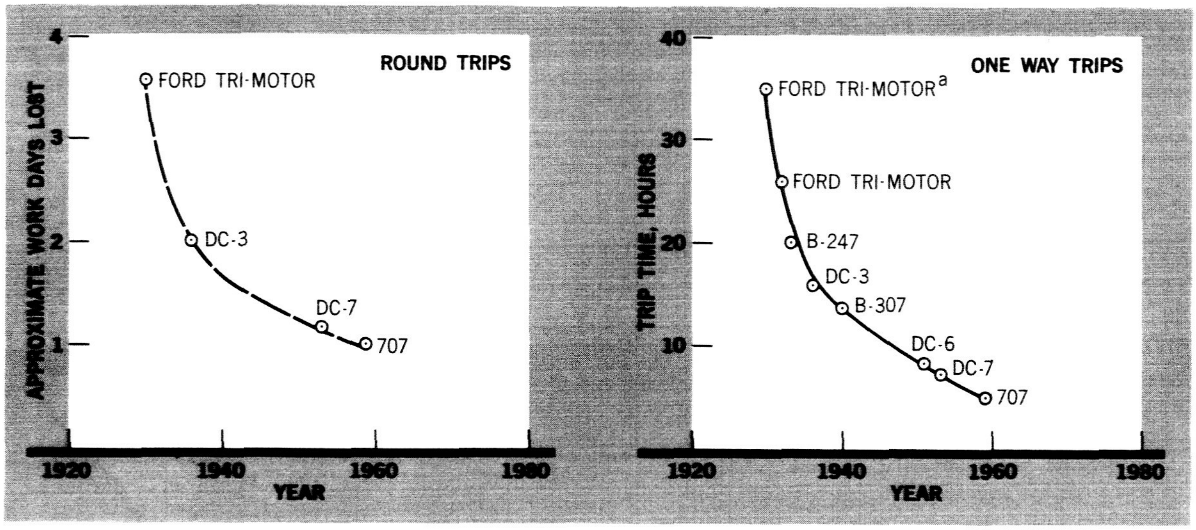


Figure 3.8. Variation of average passenger revenue per revenue passenger-mile for U.S. domestic trunk service. *Source: Based on ref. 1.*

89 billion revenue passenger-miles in 1969 domestic scheduled operations. If the fare had been 1.6¢ per passenger-mile higher, the additional cost to the traveling public in 1969 would have been almost $1–1/2 billion. The Washington, D. C., to Los Angeles coach fares, for example, would have been about $185 instead of $146. The newer aircraft also provided more convenient, more comfortable, and faster service. For example, in late 1930 the first regular all-air single-carrier cross-country passenger service was initiated. Some 35 hours and 11 stops after leaving New York – including an overnight stay in Kansas City – the flight arrived in Los Angeles. In 1970, one leaves New York and some 5 hours later lands at Los Angeles – a nonstop trip with a meal and a motion picture along the way.

Figure 3.9 shows the chronological development of trip time from New York to Los Angeles. During the 20 years from 1940 to 1960, the one-way trip time was reduced from about 14 hours to about 5 hours. Adding in the 3-hour time-zone difference for the eastbound flight gives an indication of the approximate work days lost in a round trip across the United States. If airline schedule times had not decreased as a result of R&D effort and if the same traffic had been generated in 1968 between New York and Los Angeles, 1,360 man-years of potentially productive time would have been lost in travel on this route alone (assuming, as ref. 1 indicates, that 50% of the traffic was business traffic). The losses should, of course, be multiplied several times by other coast-to-coast traffic. If, through a vigorous R&D program, the objections to overland flight of a supersonic transport could be eliminated, with the traffic growth expected by 1980, the saving in business man-years on the New York–Los Angeles route alone would be well over 5,000.

In the late 1950's, Government and industry began to consider the introduction of a supersonic transport into our air transport industry, and a Government-industry team was established to investigate its economic feasibility. Such an aircraft could substantially improve air service to all



[a]*Overnight stop at Kansas City.*

Figure 3.9. Historical trip time between New York and Los Angeles.

parts of the world. Supersonic transports could materially improve the current air transportation system by reducing flight times, saving valuable manpower for productive work by making international trips a few hours long and making commuting to Europe a reality. Perhaps much more important, a later generation supersonic transport could bring the Far East as close to the United States as Europe is today.

Noise and sonic boom are still major problems but continued R&D by the Government-industry team will, hopefully, provide an environmentally compatible aircraft that can operate out of existing airports.

VEHICLE FINANCING

Currently, U. S. manufacturers have made heavy capital investments in the development and production of new long-haul aircraft now coming on the market. Some 5 to 10 years of aircraft sales are normally required to reach a break-even point. Similarly, the airlines must go heavily into debt to purchase new equipment. A period of 5 to 10 years is required to amortize this debt. As a result manufacturers and airlines are currently in a poor financial position to develop or purchase totally new types of aircraft. Thus, for the next 5 to 10 years airline purchases will, for the most part, be 747's, DC–10's, and L–1011's, with possibly a few Anglo-French Concordes. By the early 1980's, if the U. S. manufacturers and the U. S. airlines are in an improved debt position, it may be expected that they will be actively considering new families of aircraft.

In the past, Government R&D has supplied much of the basic technology that made possible improvements in operating costs, speed, range, and comfort. During the 1940's and the early 1950's, much of the new technology was developed for and applied to military aircraft. The swept wing and jet engines were demonstrated on military aircraft, for example. This reduced risk and R&D expense to the industry in developing new commercial vehicles. Despite this, however, development costs associated with a new transport have grown out of all proportion to the assistance rendered by the Government. For example, costs rose from $300,000 for the DC–1 and –2 to more than a billion dollars for the new wide-body jets. If the military-funded contribution to new technology over the next few

years is decreased for any reason, the rate of advancement in the development of future transport aircraft will suffer unless there is some compensating increase in civil R&D. Without demonstration of new technology and new concepts, the risks to the industry will be too large for it to assume.

THE AIR TRAFFIC CONTROL SYSTEM

Increasing airline traffic requires improved systems to permit efficient traffic flow from one airport to another. Long-haul systems operate reasonably well at this time with the current instrument landing system, controlled airways, radar surveillance, control towers, and air traffic control centers. However, a reduction in the block of air space assigned to an aircraft, a fully operational area nagivation system, and a safe, efficient all-weather landing system will be required to accommodate the expected traffic growth in the near future. This will require extensive R&D. A fully operational all-weather landing system would eliminate diversions due to weather. No figures are available on an industry-wide basis for weather diversions, but it is known that one airline experienced 500 such diversions between July 1, 1968 and July 1, 1969. At an estimated cost of $2,000 per diversion, it is estimated that the cost to the air carriers was $12 million in 1969. The cost is expected to increase to about $20 million a year by 1985 if a solution to the problem is not found. The solution requires a systems approach involving design of airports, vehicles, and the air traffic system.

CONGESTION IN AIR TRAFFIC AT AND IN VICINITY OF AIRPORTS

The terminal areas are particularly hard-pressed because of increases in the number of aircraft operations. Although some steps have been taken to provide fast, efficient handling of aircraft in the air and on the ground, some major terminals have already reached or exceeded their optimum capacity. The resulting congestion not only reduces the time advantage of air travel but also increases operational costs to airlines.

The estimated costs of terminal airline delays have increased rapidly over the last six years (Fig. 3.10). The estimated cost of delays in 1969 ($158 million) is about three times the airlines' total earnings of $53 million. More than 22 million passenger-hours (with a value of about $90 million) were lost. R&D is needed in both the air traffic system and in airport design if this trend is to be reversed.

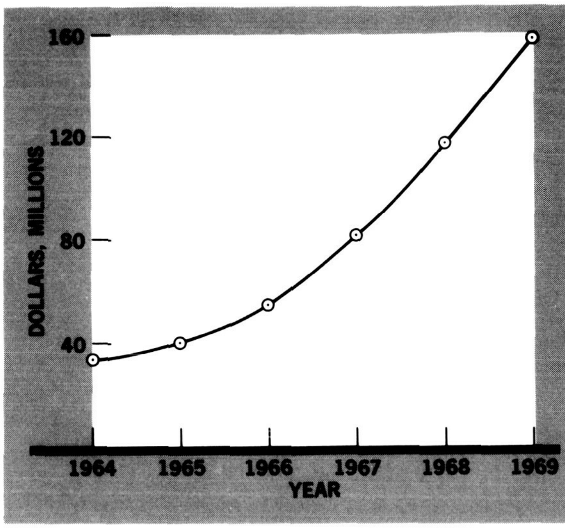


Figure 3.10. Estimated U.S. airline cost for terminal area delays. *Source: Ref. 4.*

Figure 3.11 shows an all-too-familiar scene at many of our busiest airports — one which results

Figure 3.11. Aircraft waiting for takeoff. (Courtesy of the Port of New York Authority.)

in lengthy delays for departing flights. The problem has been alleviated to some extent in some of the more active airports by limiting the number of operations per hour. This is only a stop-gap solution.

AIRPORTS

The airport is the interface between ground transportation – that provides the passenger access to and egress from the airport – and air transportation. It suffers, therefore, from a number of problems over which the airport operator has little or no control. However, a major problem over which the operator does have some control is the peak-hour saturation which exists at some of the Nation's major airports.

One of the most critical problems today is providing runways, ramps, taxiways, etc., to keep up with the rapidly increasing numbers of aircraft. The most obvious solution is to provide parallel runways. Improved air traffic control systems (and research on the effect of the several factors that influence runway separation required for safety) may reduce the separation requirement below the currently required 5,000 feet. In some cases, this will allow using existing parallel runways that are separated by less than 5,000 feet. This advantage may be offset by the trailing vortex system left by the passage of large aircraft (see Fig. 3.12). These trailing vortices might, for example, drift across both runways and actually reduce the acceptance rate. R&D is needed to permit detection and alleviation of vortices. Such research might, in some cases, provide increased airport capacity without additional runway construction.

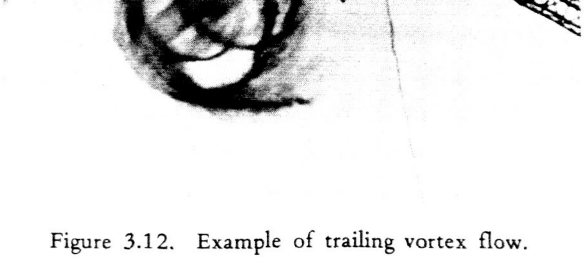


Figure 3.12. Example of trailing vortex flow.

NOISE AND POLLUTION

In recent years, the airport has changed from a good neighbor (often a city showplace) to a marginally accepted neighbor – accepted only because it is a necessary part of the air transport system. People recognize the need for new airports but, because of noise, pollution, and ground congestion, want them in someone else's backyard. An R&D program directed toward reducing aircraft noise could reduce the opposition to close-in airport locations. This would save millions of dollars by shortening access highways and ground-transportation distances.

Noise currently limits the hours of utilization of some airports. At many airports (Washington National, for example) jet operations are not scheduled from 11:00 p.m. to 7:00 a.m. In long-haul operations, such restrictions reduce the usable departure "windows" because of time-zone differences between airports. Flights with arrivals and departures near the curfew must often be diverted or cancelled, resulting in extra costs to the airlines, time lost, inconvenience to the passenger, and disruption of the system by having aircraft at the wrong airport as a result of the diversion. Figure 3.13 illustrates the problem. If Vancouver were to establish a curfew similar to the one at Montreal and London, a flight from Vancouver, British Columbia, to Montreal, Quebec, to London, England, would have to leave Vancouver between 10:30 a.m. to 2:00 p.m. or 10:30 p.m. to 11:00 p.m. If the flight were required to go beyond London to a destination with a curfew, it might be forced to lay over for 8 hours at one of the airports. If air transportation is to benefit from the speed and productivity of which advanced transports will be capable, R&D on noise alleviation must be accelerated.

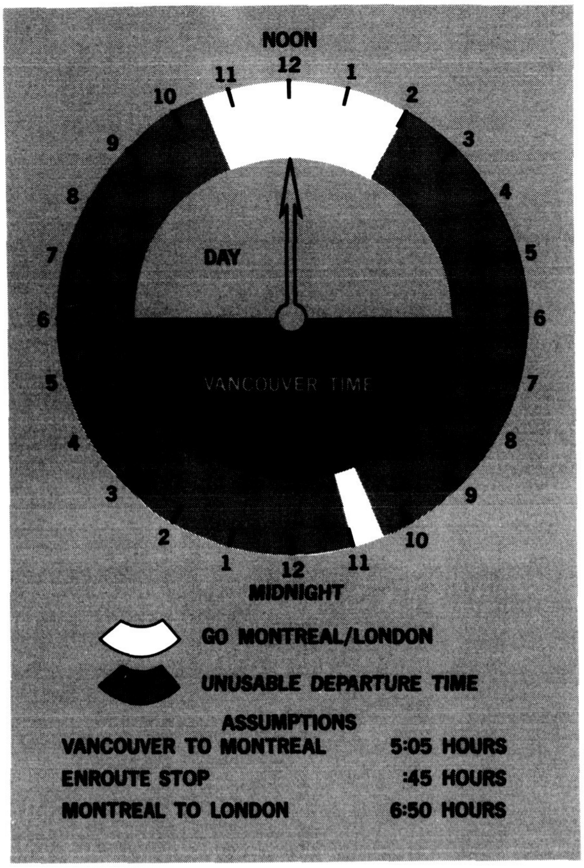


Figure 3.13. Effect of noise curfew on available departure times.

Airports of the future must be developed through a systems approach. The approach must include ground transportation to and from the airport, passenger-processing, baggage-handling, aircraft-servicing, and field layout that reduces taxi time and aircraft congestion. R&D in all these areas is urgently needed to assist local communities in designing their airports. It is recognized that several solutions to the access/egress problem have been tried or are planned for the future. Although this particular service is not necessarily the responsibility of the airport, it must be considered in planning any future airport.

RECOMMENDATIONS AND POLICY

Because of the importance of long-haul transportation to this country, the part it plays in allowing U. S. industry to expand its operations by providing quick reaction time, and the vast amount of business the sale of aircraft overseas generates in our aerospace industry, the following policy should be pursued:

- Continuation of the current policy of Government-industry partnership in advancing the state of the art. This means that both civil and military agencies of the Government must maintain a vigorous R&D program to provide the data needed to insure a healthy aircraft industry.
- New ways of financing the manufacture and purchase of aircraft may be needed because of the large financial burden the new sophisticated transports entail and the added risk resulting from advancing the state of the art. Exploration of possible courses of action should be begun without delay to permit continuation of the customer-manufacturer relationship that has resulted in the United States being the major source of superior transport aircraft for the world over the last 40 years. Possible financing procedures that could be used to assist the industry are: some form of tax relief; guaranteed loans at reasonable interest rates; free use of Government research facilities during the design stages of development; and Government support of aircraft during certification tests.
- The U. S. Government should take a more active role in the flight testing of advanced aircraft designed to prove new technology and to provide a base from which regulations can be established.

SHORT-HAUL SYSTEMS

BACKGROUND

The use of air travel for short trips (less than 500 miles) has sharply increased in recent years, providing travelers in smaller cities and less densely populated areas with a quick, convenient,

and effective way to tie in with long-haul air systems. It also provides an increasingly popular means of short-distance intercity travel, particularly where surface modes are rapidly becoming congested or inadequate. Approximately 60% of all domestic air passenger movements and 80% of all domestic air carrier aircraft movements cover less than 500 miles. One-third of the passengers and two-thirds of the aircraft fly less than 300 miles.

The potential growth of short-haul air travel is very high because only a small portion of the large travel markets to be served at short distances are now accommodated by air (see Table 3.1). Short-haul travel demand (all modes) could be expected to increase at least twofold by 1985. The automobile will doubtless remain the principal means of short-haul travel, but highway systems, particularly at junctions in large urban centers are rapidly approaching saturation. Increasing public concern over preservation of the natural environment makes it difficult to expand highway capacity in many areas.

Increased use of common-carrier (bus, rail, and air) modes will be required to relieve the strain on the highway systems. Air systems can be expected to take over portions of the total demand, because the inherent route flexibility of the air mode enables it to respond relatively easily to increases and shifts in travel demand. A fundamental difficulty, however, in achieving profitable operations over short distances by helicopter, air taxi, commuter, local services, or trunk-line operators, shows up in Figure 3.14. Operating costs

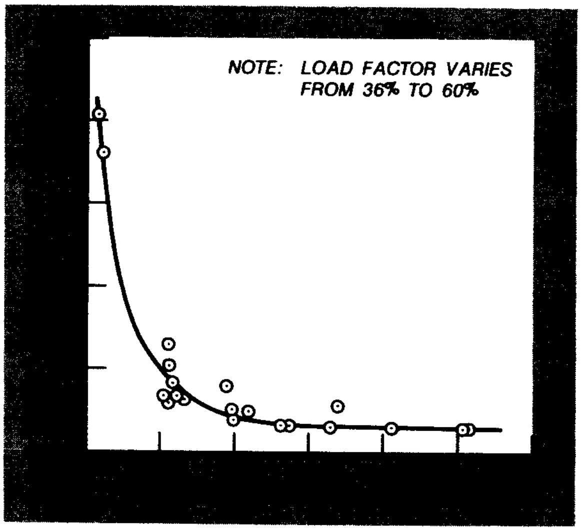


Figure 3.14. Average direct operating costs—domestic trunk, local service, and helicopter airlines, 1968 and 1969. *Source: Ref. 2.*

TABLE 3.1. PERSON–TRIPS FOR 1967

ONE-WAY TRIP LENGTH, MILES	MILLIONS OF PERSON-TRIPS						
	AUTO	BUS	RAIL	AIR	WATER	COMBINATION OF TWO OR MORE MODES	TOTAL
LESS THAN 50 [a]	35.8	0.8	0.4	0.1	0.3	0.1	37.5
50-199[a]	181.4	4.9	1.8	2.2	0.2	1.4	191.9
200-499	57.6	2.2	1.2	8.8	0	1.7	71.5
500 AND OVER	26.5	0.9	1.7	14.4	0	1.5	45.0
	PERCENT OF TOTAL						
LESS THAN 50	95.4	2.2	1.0	0.3	0.8	0.3	100.0
50-199	94.5	2.5	1.0	1.2	0.1	0.7	100.0
200-499	80.7	3.1	1.6	12.2	0.0	2.4	100.0
500 AND OVER	58.9	1.9	3.8	32.1	0.0	3.3	100.0

[a]*Trips under 100 miles from home were excluded when an overnight stay was not involved. Trips of 100 miles or more were included regardless of whether an overnight stay was made. Source: Ref. 5.*

increase sharply at trip distances less than about 200 miles. As may be seen from Figure 3.5, helicopter airlines and local service carriers are flying average stage lengths of 18 and 145 miles, respectively; commuter airlines are averaging stage lengths of less than 100 miles. All these stage lengths are at the high-cost end of Figure 3.14. With the intense competition from other modes for short stage lengths, it is impossible to establish a fare curve to match the operating cost curve. Only the trunk lines can afford to underwrite the higher costs of short trips with revenues from their more profitable longer routes.

In short-haul operations, delays caused by airport and air traffic congestion and ground access time amount to a substantial portion of the total trip time. Increasing public opposition to airports in populated areas because of noise can add substantially to access-time requirements and further reduce the effectiveness of short-haul air travel.

OBJECTIVES AND ALTERNATIVES

Objectives

To relieve constraints on short-haul aviation systems, changes and improvements must be made with four basic objectives in mind:

- Economic viability with minimal Federal support or subsidy.
- Fast and highly dependable service integrated effectively with long-haul air transportation and ground circulation and distribution systems, and providing a high degree of passenger convenience and comfort.
- Noise and pollution levels at or below acceptable community requirements.
- Operational safety of high level under all operating conditions and categories of service.

Both interurban and intraurban missions were examined in this Study. Attention was focused on three principal categories of interurban service: point-to-point service in low-density areas; feeder service from low-density to high-density areas; point-to-point service in high-density areas. These were examined in three representative geographical areas: the Northeast Corridor; the north central region of the United States; and the western mountain states region. Intraurban service was evaluated in three metropolitan areas: Boston, Detroit, and the San Francisco Bay region.

Alternatives for Feeder and Low-Density Operations

At the beginning of 1969 there were 9 local service air carriers operating out of 460 airports in 47 of the 48 contiguous states. They provided excellent service to some 141 million people – 97% of the metropolitan population (ref. 5). During 1969, despite receiving $36 million in subsidies, these airlines suffered a net loss of $63 million, compared to the net profit of $91 million by the domestic trunk airlines (ref. 6). Local service operation involves a large number of low-traffic points. Local carriers serve approximately twice as many points as trunk lines, incurring higher costs per revenue passenger-mile, particularly in aircraft- and traffic-servicing. With today's aircraft, more stops at shorter stage lengths raise direct and indirect operating costs (Tables 3.2 and 3.3).

Currently, the best available short-haul aircraft are 80- to 115-passenger jets. But, for the sake of economy, the new jets are being used predominantly on longer routes, while smaller 40- to 60-passenger turboprop aircraft, formerly used in the long-haul fleet, are relegated to the lower density, short routes where average loads are about 20 passengers. Such operations have not been profitable. Operating statistics show that average turboprop load factors are about 45%, although approximately 60% are required to break even with existing fares (ref. 2). The CAB has recently sought to provide "route strengthening" by awarding longer and more profitable routes to certain local service carriers, authorizing changes in the fare structure, and honoring requests by

TABLE 3.2. OPERATING STATISTICS, 1969

ITEM	LOCAL SERVICE CARRIERS[a]	DOMESTIC TRUNK CARRIERS
AVERAGE PASSENGER TRIP LENGTH, MILES	273	769
AVERAGE STAGE LENGTH, MILES	145	505
AVERAGE NUMBER OF STAGES PER TRIP	1.9	1.5
TOTAL OPERATING COST, CENTS/REVENUE PASSENGER-MILE	9.96	6.11
TOTAL REVENUES, CENTS/REVENUE PASSENGER-MILE	9.70	6.44

[a]*Includes subsidies.*

Source: Refs. 1,2,6.

TABLE 3.3. INDIRECT OPERATING COSTS, 1969

SERVICE	COST PER REVENUE PASSENGER-MILE, CENTS	
	LOCAL SERVICE CARRIERS	DOMESTIC TRUNK CARRIERS
PASSENGER SERVICE	0.61	0.63
AIRCRAFT AND TRAFFIC SERVICING	2.29	1.08
PROMOTION AND SALES	0.92	0.73
ADMINISTRATIVE	0.54	0.26
TOTAL	4.36	2.70

Source: Ref. 6.

the local service carriers to drop service on unprofitable routes. Nearly one-quarter of the points served by local service carriers generate less than 15 passengers per day (ref. 7).

Third-level carriers (the commuter airlines) are now taking over some of the short, low-density routes. At present, however, they are restricted to aircraft of less than 12,500 pounds gross weight (airplanes, developed principally for the general aviation market, of about 20-passenger capacity or less) unless specifically authorized by the CAB (ref. 8). The CAB is currently investigating the possibility of liberalizing this restriction. These carriers operate without subsidies, route protection, or CAB certification, and are thus highly vulnerable to the hazards of the market.

Separate analyses were made of commuter and local service requirements to meet the anticipated 1985 travel demand in two representative areas: one in the western states centered around Salt Lake City (for low-density operation) and another centered at Chicago, out to about a 250-mile radius (for feeder operations) (Fig. 3.15). (Analyses covering operations in the high-density Northeast Corridor are discussed later in this section.)

The low-density short-haul air travel market for 1985 was projected to be five times the 1968 level. A family of four sizes of CTOL aircraft (8-10 seat, 20-30 seat, 60-70 seat, and 130-140 seat) was considered needed by the commuter and local service carriers.

The variation in break-even load factor with aircraft size, determined on the basis of 1969 cost data (Fig. 3.16), indicates that to be profitable at load factors of about 50% on short routes, present-day aircraft must be at least in the 80 passenger size class or larger. Thus existing turboprop equipment just barely begins to break even.

An estimate of the price-versus-size relationships, for a nominal break-even load factor of 50%, was made to indicate where improvements may be needed in the future (Fig. 3.17). To maintain a break-even load factor as the number of seats is reduced, the aircraft price must be reduced sharply because crew, fuel, and maintenance costs do not decrease in direct proportion to seating capacity. Consequently, price-related items must be reduced faster than in direct proportion. If future feeder and low-density

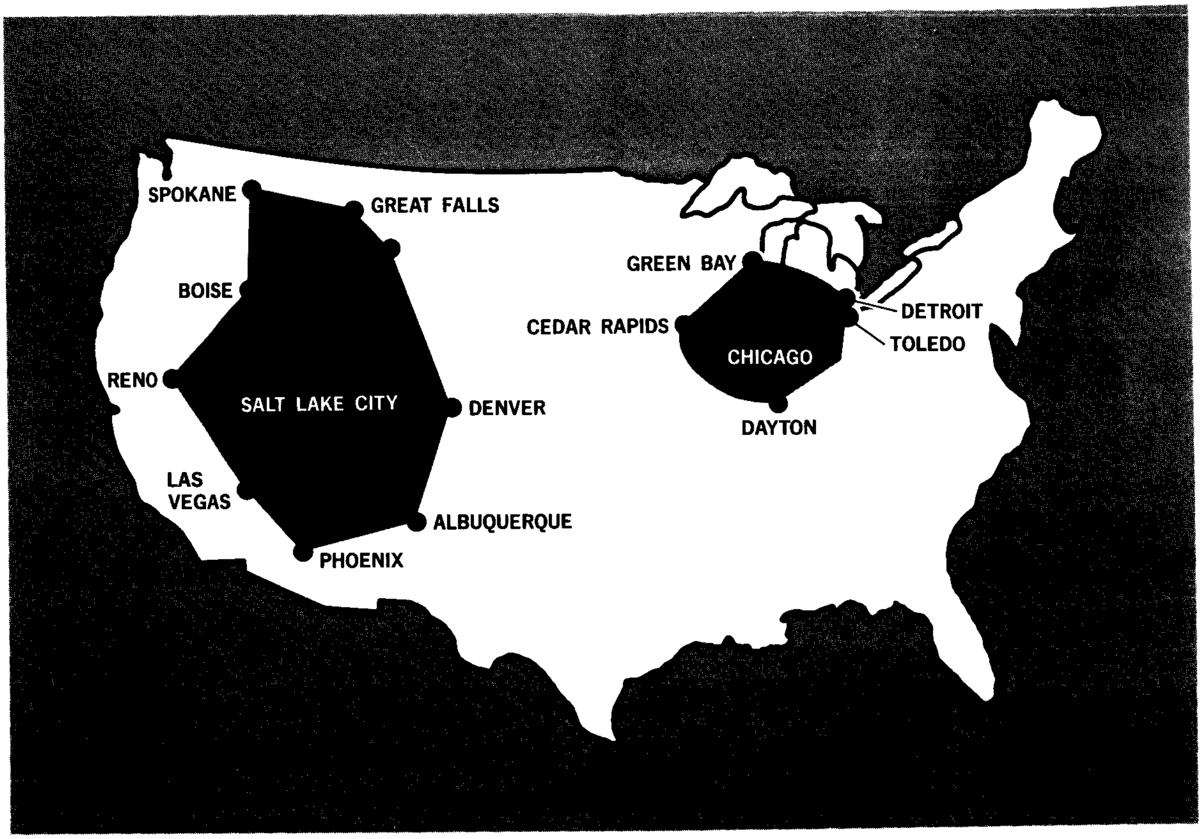


Figure 3.15. Regions considered in analysis of low-density and feeder operations.

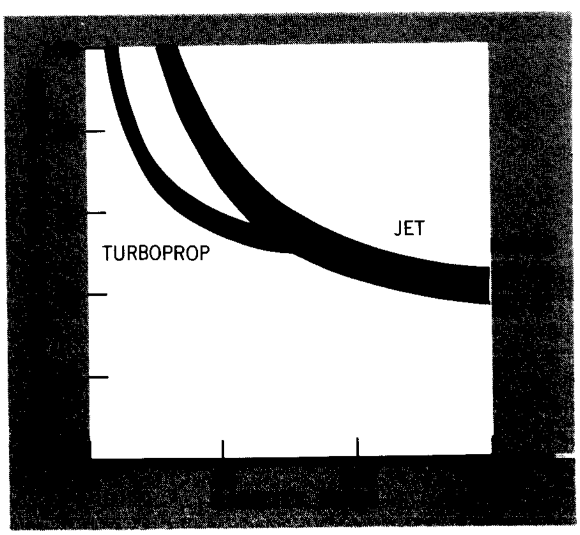


Figure 3.16. Break-even load factors.

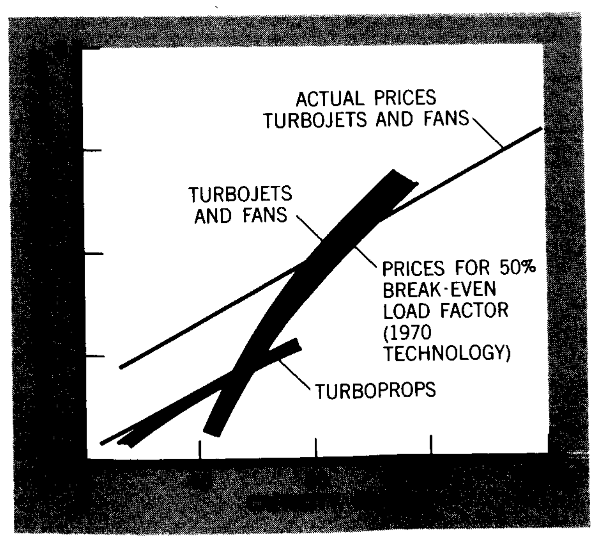


Figure 3.17. Price versus size relationship for a break-even load factor of 50%.

short-haul systems are to operate at a profit, some or all of the following changes are essential:

- Significant reduction in initial costs
- Reduced crew expense
- Reduced maintenance costs
- Increased fares
- Increased subsidies to airlines
- Financial assistance to manufacturers

Of the principal components of direct operating cost (crew, fuel, maintenance, and depreciation), crew costs are the least susceptible to reduction by R&D. Fuel costs may be cut through improved engine efficiencies, and reductions in airplane drag and structural weight. Maintenance costs may be reduced through system simplification and improvements in component reliability. Depreciation, directly related to initial costs, might be reduced through a careful balance in improvements in propulsion, airplane weight reduction, and simplicity.

One of the most promising alternatives is to apply R&D toward new aircraft designs optimized for economical operation on low-density, short-haul routes. Regulatory action may also be needed for route protection, for financial assistance for the commuter airlines, for increasing the permissible weight of commuter and air taxi aircraft, and for modifying the fare structure or subsidies for local service operations.

Alternatives for High-Density Operations

Operations in high-density areas encounter all of the problems constraining the effectiveness of the short-haul air system. Very large travel markets exist in high-density areas, but the air systems have only a small share. They cannot yet compete with the automobile in convenience and out-of-pocket costs. Air carriers in general have suffered financial losses operating short stage lengths even in the high-density areas. At the major hub cities, access/egress and congestion problems are particularly severe and it is not unusual for the travel time to and from the airports to exceed the air trip time. Short-haul and long-haul operations usually share the same airports, straining the capacities of both systems, but there has been widespread opposition to new or more convenient airports.

A course of action would be to improve the existing system. Improvements would include developing new conventional takeoff and landing (CTOL) aircraft with low noise and low operating costs at short ranges; building new airports; increasing the capacities of existing airports and the air traffic system; and expediting passenger handling and processing, by means of limited- or exclusive-access high-speed ground transportation and intraurban air feeder systems for the airports. Some of these improvements have been initiated or are planned in a few locations.

It has been suggested that systems built around short takeoff and landing (STOL) and vertical takeoff and landing (VTOL) vehicles would provide the best short-haul travel in high-density areas. It is expected that STOL aircraft will first begin operations from conventional (CTOL) airports, but to realize the full advantages of STOL and VTOL operation, new airport concepts ("STOLports" and "VTOLports") will be needed. Figure 3.18 shows one such concept.

Such systems, operating closer to origins and destinations, would provide better service with

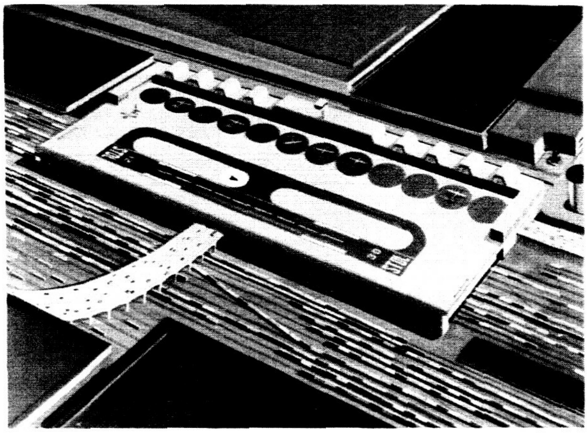


Figure 3.18. Elevated STOLport. *Source: Ref. 9.*

substantial savings in total travel time. They would also relieve the strain on long-haul systems by moving away from major airports those flights not requiring interline transfers. Noise and pollution would be reduced by steep, curved, and short-duration approaches to landing areas. The total systems approach, which would be essential to the realization of such systems, would require complete cooperation between numerous and diverse political, business, private, and Government interests.

Analyses of the costs and possible future patronage of STOL, VTOL, and CTOL systems in 1975-1985 were made by extending previous work by DOT in the Northeast Corridor Transportation Project (NECTP). The NECTP techniques and demand simulation models were used to examine the sensitivities of several trade-off factors, including terminal locations and numbers, access/egress characteristics, system operating costs, demand levels, population distributions, competing travel modes, and land costs versus vehicle costs to alleviate noise. Various STOL, VTOL, and CTOL systems were considered as possible alternatives in a multimode situation, against alternative mixes of competing surface systems that included the tracked air-cushion vehicle (TACV) along with the auto, rail, and bus modes. The air systems were treated as viable commercial endeavors and were required, with changes in fares, to show a return on investment after taxes. It was assumed that the Airport and Airways Trust Fund would provide the local public authority with 50% of the investment capital for land, structure, and equipment for runways and taxiways plus 100% of investment and annual cost for air traffic control. The local public authority was assumed to provide capital for the remainder of the terminal investment (via a bond issue for example) and to own, operate, and maintain the terminal. The aircraft operator would provide his own staff in the terminal and would pay, via rental and landing fees, the full annual cost to the public authority.

The NECTP analyses emphasize the importance of terminal location for the short-haul mission. In the simulations, air travel patronage increased significantly as total travel time decreased. Door-to-door trip time was found to be the strongest single factor affecting the patronage of the short-haul air systems, particularly in the business travel market. Consequently, even though their fares were higher than CTOL, STOL and VTOL systems attracted the highest number of air travelers because their terminals were located in centers of high demand, where access/egress time was reduced and low door-to-door trip times could be achieved (see Fig. 3.19 and Table 3.4).

The lower total trip times for the STOL and VTOL systems can be seen in the figure. The STOL and VTOL central business district operations resulted in the highest overall patronage (Table 3.4) even though their fares were highest (Fig. 3.19). Very little difference was seen between the VTOL and 1500-foot STOL systems. The nearly equal costs (fares) shown in Figure 3.19 reflect the nearly equal trade-off between the higher initial investment and DOC of the VTOL and the higher Federal and local investment in STOL airports for the STOL aircraft (partially passed on to the operator in landing fees). The nearly equal trip times and patronage resulted from the comparable performance of the two vehicles. (The VTOL version tested for 1985 was a tilt-wing turboprop with lower cruise speed than the fanjet STOL – hence, the slightly longer total trip time and lower patronage.)

The feasibility of locating air terminals in city centers will depend strongly on many factors, including safety, noise, and air pollution. Trade-off studies indicate that definite benefits could be gained through noise-suppression treatment of aircraft engines and through increased climb angles possible with VTOL and STOL aircraft. Simulations were made using a tilt-wing turboprop VTOL, with and without noise-suppression equipment, flying at climbout angles of 15° and 30°. The results were compared in terms of costs to the operator (reflected in increased fares) for the installation of

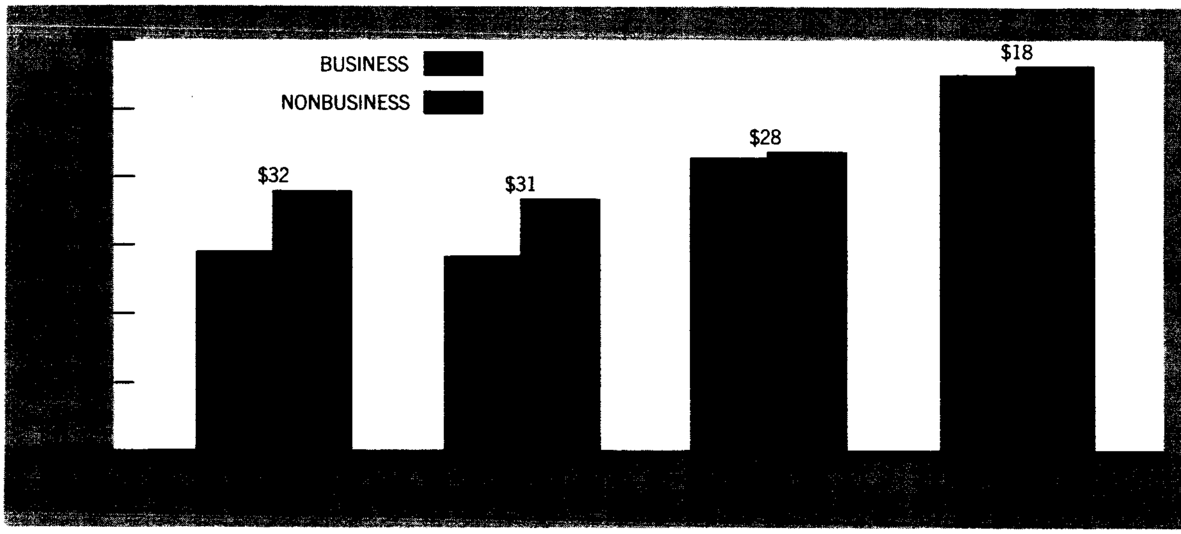


Figure 3.19. Total door-to-door trip time and fares for business and nonbusiness travel, Washington-New York City, 1985.

TABLE 3.4. NORTHEAST CORRIDOR MODAL SPLIT, 1985, PERCENT OF TOTAL

MODE	OPTIONS			
	VTOL CBD	STOL CBD	STOL SUBURBAN	CTOL
AUTO	70	69	73	75
RAIL	13	13	15	17
BUS	4	4	5	5
AIR	13	14	7	3

noise-suppression equipment and for the acquisition of property required as a noise buffer zone. For a 15° climb angle, with noise suppression equipment, land cost would be 75% less than if no noise suppression equipment were used. Without the equipment, land would cost 38% less for a 30° climb angle than for a 15° angle.

Significantly, the tracked air-cushion (ground) vehicle (TACV) appears attractive as an alternate high-speed, short-haul travel mode for the Northeast Corridor. For 1985, the corridor could use a tracked air-cushion vehicle with a 300-mph cruise speed operating on a spinal route among the major cities. On routes out to 200 miles, TACV would be competitive with STOL or VTOL in fare, door-to-door trip time, and service frequency, and definitely superior to CTOL. Future planning for short-haul requirements must, therefore, consider high-speed ground competition, particularly in high-density regions.

In any case, STOL or VTOL systems offer promising solutions for high-density, short-haul operations.

INTRAURBAN TRANSPORTATION SYSTEMS

Improved intraurban transportation is essential for relieving growing highway congestion. Expansion or modernization of the existing highway system is only part of the answer. Preferred would be a fully integrated system incorporating an expanded highway network and complementary fast urban mass transportation system. Current urban mass transportation systems favor rail or subway systems supplemented by bus routes. Future planning is built around improvements to these same systems (ref. 10).

To be most effective, mass ground transportation systems require:

- An exclusive ground right-of-way.
- High-density corridors where there are predictable passenger travel patterns and a favorable topography.

- Approximately 5 to 8 years to plan, build, and start operation, or 2 to 4 years to expand an existing system to meet new demands, even under favorable economic and political conditions.
- Cooperation of local governments and agencies along the entire route.
- A relatively large initial investment.

An air transportation system, with freedom from community-disrupting ground corridors, offers advantages in all these areas, plus the following unique advantages:

- Collection, distribution, and transfer of interurban passengers to and from airports and metroports.
- Public transportation to and from a large city and its surrounding new towns or satellite developments.
- Public transportation between complexes within existing relatively low-density, "urban sprawl" areas (such as Los Angeles).
- Public transportation over geographic barriers (water, mountains).

An intraurban transportation system is quite dependent upon the peculiar demographic characteristics of the metropolitan area. Therefore, each area must be evaluated individually to determine the best system for its particular needs.

Intraurban air transportation systems have been tried in four metropolitan areas (Los Angeles, New York, Chicago, and San Francisco-Oakland), but have met with only token success. Supported by subsidies, these systems grew and provided a fast, but infrequent, alternative to ground modes of transportation. In 1965, Federal subsidies to helicopter airlines were terminated by the Congress. Although the number of passengers continued to rise for a few years (see Table 3.5), Congress' action marked the decline of helicopter airlines within the United States.

TABLE 3.5. HELICOPTER CARRIERS – NUMBER OF ORIGINATING PASSENGERS IN SCHEDULED SERVICE

1957 - 153,000	1963 - 458,000
1958 - 230,000	1964 - 608,000
1959 - 366,000	1965 - 718,000
1960 - 490,000	1966 - 1,067,000
1961 - 431,000	1967 - 1,222,000
1962 - 359,000	1968 - 1,042,000
	1969 - 737,000[a]

[a]*Los Angeles Airways strike.* *Source: Ref. 1.*

One reason the subsidies were terminated is that the service was considered to benefit a select market (primarily businessmen) rather than the public as a whole. The Congress reasoned that scheduled helicopter service should therefore run on an adequate fare structure. Or, if airlines considered the service necessary as a feeder operation, they should subsidize the service. San Francisco and Oakland Helicopter Airlines, New York Airways, and Los Angeles Airways were in fact so subsidized for varying periods.

Only New York Airways and San Francisco and Oakland Helicopter Airlines continue to provide scheduled service. Chicago Helicopter Airways terminated its scheduled service to coincide with the cancellation of subsidy payments. Los Angeles Airways, after operating 5 years without Government subsidies and 2 years without financial support from the trunk airlines, filed for bankruptcy in October 1970. San Francisco and Oakland, which never received Federal subsidy payments, is now operating on a reduced schedule after filing for bankruptcy in 1970. New York Airways continues to operate as a scheduled carrier because certain trunk airlines provide financial and service support.

Because of high operating costs of current VTOL aircraft, poor utilization, and the necessity to maintain a fare structure competitive with the other modes of urban transportation, commercial scheduled systems as currently constituted are

not economically feasible without subsidies. The problems are aggravated by extremely short stage lengths (averaging 18 miles for the helicopter airlines) and the commuter-peaking problem.

Because of their special characteristics, however, VTOL aircraft – including helicopters – appear to offer certain interesting possibilities to help solve the problems of transporting passengers between major airports and urban areas.

Alternatives for Intraurban Transportation Systems

An analysis of a typical urban transportation system indicates that trips of 30 minutes or less (approximately 20 miles) can be made faster by automobile than by mass transportation systems. To gain patronage, any mass transportation system must provide faster service in the 20 to 50 mile range. The most attractive possibilities appear to be either a fast transit link (FTL–an improved rapid rail transportation system) or an air system.

The FTL system would consist of automatically controlled vehicles capable of operating either independently or as trains. The vehicle envisioned for 1985 would be quiet, lightweight, and low-profile. It would require less precision in guideways than current rapid transit systems, such as the San Francisco Bay Area Rapid Transit (BART). The FTL could be underground, on the ground, or elevated, and would travel on exclusive rights-of-way (ref. 10)

An airbus system built around STOL or VTOL vehicles would also provide an attractive alternative to the auto for fast intraurban travel (refs. 11, 12, 13). One study (ref. 11) indicates that an operating subsidy would be required for a STOL or VTOL system. It appears possible, however, that R&D can eventually make possible a system where operating costs can be met and the initial investment in aircraft can be paid off.

Another alternative would be an improved helicopter taxi service. The helicopters would operate from major airports to relatively austere helipads at scattered industrial sites and motels, often eliminating the need for any ground transportation. They would provide demand service rather than scheduled service, and would not require terminal services such as ticketing or baggage-handling. Among the improvements which appear possible are instrument flight capability, increases in speed and range, and reduced operating costs.

In an analysis performed for the Joint Study, it was concluded that both an airbus system and a helicopter taxi service can operate within the same metropolitan area in a complementary fashion, similar to ground buses and taxicabs. It was also concluded that a combination of the options may be preferable for a given metropolitan area. The fast transit link has definite advantages for the mass movement of people along fixed routes. However, the advantages of an air system – speed and flexibility – encourage its consideration for urban transportation. Intraurban air systems, while not economically viable today, could be an important element of future urban transportation systems if R&D is continued to reduce operating costs and improve service dependability to the point that these systems could operate with subsidies no greater than those for rapid transit.

BENEFITS

Benefits from the improvement of feeder and low-density, short-haul systems, from the implementation of effective STOL and VTOL interurban systems in high-density areas, and from intraurban air systems in large- and super-demand centers would include:

- More frequent service to low-density areas and new service to more low-traffic-generation points.
- Reduction in total trip time in high-density areas.
- Increased airport and airways system capacities in high-density areas.

For the general public and the Nation, benefits would include:

- Reduction in required subsidies.
- Contribution toward a balanced transportation system.
- Reduction in highway congestion.

R&D REQUIREMENTS

To achieve improved short-haul systems will require a broad-based R&D program covering all systems elements, as summarized below:

Air Vehicles

The major thrust of R&D programs for short-haul vehicles should be to continue to provide a broad base of technology on which specific vehicle designs can be based when the operational needs have been defined. Major emphasis should be placed on those systems having the greatest potential for achieving the following:

- Safety under all operating conditions.
- Low noise for both approach and takeoff.
- Flight control and handling characteristics suitable for steep descent, curved approaches to minimum-length runways, and maximum automation of the approach and landing, with maximum safety under all conditions to include operation in wake turbulence.
- Low direct operating cost, high reliability, and low maintenance costs.
- Wide public acceptance, attained by good ride quality and minimum vibration and noise.
- High cruise speed for minimum total trip time.

The Air Traffic System

The air traffic system for short-haul must be compatible with long-haul as well as other systems. For short-haul, emphasis should be on the portions of the air traffic system that will allow:

- Steep and curved instrument approach and departure routes.
- Area navigation and low-altitude air traffic control in hub areas.
- All-weather and automatic landing systems.
- Instrument landing systems at all airports served by the short-haul system and suitable for both low-density and high-density operations.

Airports and Complementary Ground Transportation

Short-haul requirements for airports and access/egress systems will generally be compatible with those of other mission areas. The principal goals for short-haul are to achieve:

- Airport designs that provide for maximum safety, to include arresting systems for elevated STOLports and VTOLports.
- Efficient passenger/cargo processing, to assure that maximum benefit is attained from reduced total trip-time capability.
- Ground access systems fully compatible with STOLports and VTOLports located within congested urban areas.

Demonstration Programs

Additional R&D in the form of proof-of-concept and system component demonstrations will be required to support any procedural, technical, or system demonstrations that may be undertaken. Because of the need to apply the systems approach to the implementation of V/STOL systems, such demonstration programs will undoubtedly be a necessary first step before V/STOL commercial service can be initiated.

Major Policy Issues

Previous studies by DOT, NASA, and CAB, and this Study as well, have indicated the need for decisions on policy regarding the role of the

Federal Government in facilitating the development and introduction of improved short-haul systems, particularly those using STOL and/or VTOL vehicle concepts. Two of the more important policy issues derived from this Study are:

- *The role of the Federal Government in planning and developing new short-haul systems.*
  - The need for the total systems approach in developing new short-haul systems, particularly STOL and VTOL systems, calls for close coordination in planning by the Federal, State, and local governments, and by private enterprise elements. Of critical importance to short-haul in the planning process are: the effective integration of urban transport systems with the air system to assure access/egress efficiency; and determination of suitable locations for new airports (including STOLports and VTOLports), as well as obtaining concurrences on these locations by state governments and local communities. A leadership role for the Federal Government is essential if progress is to be made in these areas.
  - Areas of technical uncertainty and financial risk will be encountered in developing new short-haul systems. Demonstrations of short-haul system technology, service, operating technique, and market potential will be required. Criteria need to be established for determining the extent of participation by the Federal Government in such demonstrations, particularly those designed to determine market potential.
- *Financial assistance by the Federal Government, and regulatory considerations.*
  - New short-haul CTOL, STOL, and VTOL vehicles would better meet future air transportation demands and relieve present constraints to effective operation. The development of efficient, economically viable aircraft could assure continued U. S. leadership in aircraft manufacture and sales and permit economical airline operation with a minimum of Government subsidy.
  - A third level of airline service, the commuter airlines (scheduled air taxi operations), has come into being to meet demand in low-density regions and to complement higher density local service operations. Regulatory policies restricting the size or weight of aircraft used by these operators should be modified to permit a wider choice of aircraft and thus to improve operating economics. The Federal Government should develop demonstration programs to determine whether route protection for the commuter airlines and fare/subsidy adjustments for low-density operations would be beneficial to the system and would be in the national interest.

CONCLUSIONS AND RECOMMENDATIONS

The short-haul system is an important element of the national transportation system. Substantial benefits may be expected to accrue from programs designed to alleviate the constraints to further growth of the system. The constraints are currently caused by problems with systems economics, which limit profitability; problems with access, congestion, and convenience, which offset advantages in speed; and problems with noise and environmental pollution, which limit public acceptance of the system.

Because of the diverse nature of the short-haul system, a variety of aircraft systems (CTOL, STOL, and VTOL) will be required, both to alleviate the constraints to growth and to satisfy all the needs of the system. Efficient

CTOL systems will yield the most economical and satisfactory intercity air service in most feeder operations and in virtually all operations in low-density areas. STOL and VTOL systems will be needed to provide adequate intercity service in high-density areas. Intraurban STOL and VTOL systems will be needed in some urban areas, depending on geographic and demographic circumstances. The latter systems may not be economically self-sufficient, however, for some time to come.

R&D areas requiring major emphasis are those which will make possible more efficient vehicles with better operating economics, with noise and pollution characteristics sufficiently low to gain public acceptance of the system and thus alleviate constraints to airport locations. Regulatory changes will also be required to assure the continued growth and viability of the short-haul systems.

In view of the potential for growth of short-haul air systems and the benefits to be derived therefrom, the following approach is recommended:

- Continue to assure the existence of a broad-based vehicle technology program that will encourage the development of efficient, new short-haul vehicles and help assure continued U. S. world leadership in commercial aviation aircraft. Major emphasis should be placed on vehicle operating economics and alleviation of noise and pollution.
- Assume a position of Federal Government leadership in demonstration programs for new short-haul aviation systems. Both inter- and intraurban systems should be included.

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<u>AIR CARGO</u>

THE TOTAL DISTRIBUTION COST CONCEPT

Air cargo is the fastest growing mode of freight transportation in the United States, although cargo rates have remained high over the past 20 years. The chief reason for this rapid growth is undoubtedly the great time advantage of air transport. This growth can also be attributed, in part, to the recognition and acceptance of the total distribution cost concept. Under this concept, total costs of distribution are minimized by trade-offs among packaging, transportation, insurance, warehousing, inventory levels, interest charges, materials-handling, obsolescence, loss, and damage. Earlier, these costs were treated as separate entities, without considering the interrelationships among them. Many companies are now establishing distribution departments, in some cases elevating major distribution decisions to top levels of management.

When total distribution costs are considered, air freight frequently emerges as the optimum mode of transportation for high-value commodities. In many cases savings in warehousing, packaging, and inventory costs more than offset the higher rates charged for air cargo transportation. Studies by the Air Transport Association of America (ATA) have indicated that distribution savings up to 40% may be possible for some commodities by switching from surface to air transportation.

GROWTH OF AIR CARGO

The term cargo as used here includes freight, express, and mail. Air cargo is now experiencing the rapid rate of growth that was enjoyed by the railroads and motor carriers in earlier years (Fig. 3.20). Domestic and international cargo traffic increased 455% between 1959 and 1969, compared to a growth in passenger traffic of 285% (ref. 1). The rate of growth can be expected to level off in about 15 years, consistent with growth patterns for other modes of cargo transportation. Figure 3.21 shows the growth of air cargo since 1957 and projections through 1985 based on three estimates of annual growth rates from 1969 to 1985: 12.5% (by Boeing Co.); 17.1% (by Lockheed-Georgia Co.); and 19.1% (by Douglas Aircraft Co.).

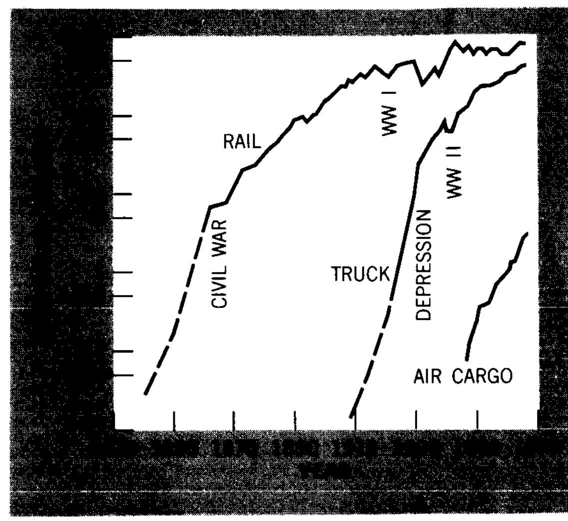

Figure 3.20. Growth of rail, truck, and air modes of U.S. domestic cargo transport (air includes supplemental carriers). *Source: Ref. 2, p. 23.*

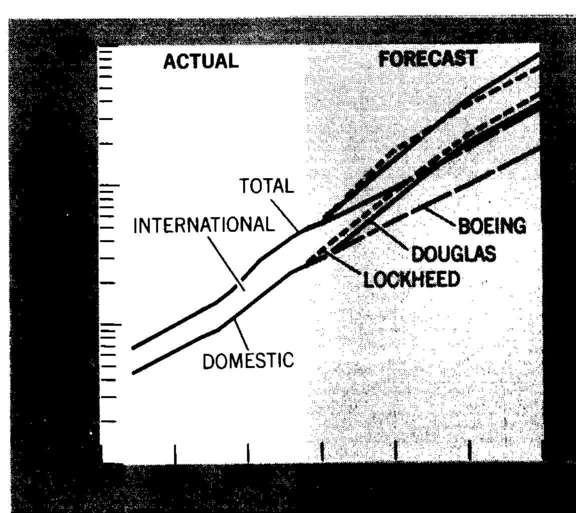

Figure 3.21. Historical and forecast U.S. scheduled air cargo, domestic and international (does not include supplemental carriers). *Source: Refs. 2-4.*

It is expected that in 1985 O'Hare Airport in Chicago will originate more than 2 million tons of cargo compared to 195,000 tons in 1968. Charlotte, North Carolina; Dayton, Ohio; Houston, Texas; and Denver, Colorado; will have a greater volume in 1985 than did O'Hare in 1968. Twenty-seven cities are expected to have more volume than the 135,000 tons of domestic cargo handled in 1968 at New York's Kennedy Airport.

MARKETING

Less than 1% of the domestic intercity cargo ton-mile market was carried by air in 1970, while the airlines reported that 67% of their belly and deck cargo cubic capacity was not used. The importance of air freight for high-value commodities may be seen from the fact that in 1969, air cargo exports and imports at the Port of New York represented only 0.59% of the weight handled, but 26.7% of the cargo value (ref. 5).

Air cargo is being used to expand many markets. Fresh Idaho trout are being flown to Eastern markets. Florida tropical fish dealers have been able to achieve lower handling costs by air shipments (ref. 6). Automobile and motorcycle parts rank first in the list of top ten commodities carried by scheduled airlines in the U. S. (ref. 7). Sears, Roebuck ships approximately 6,000,000 pounds of merchandise by air to Hawaii each year to minimize its requirements for warehousing and inventory in the Islands (ref. 8). J. C. Penney uses air freight daily to ship catalog orders from its distribution center in Milwaukee. Ohrbach's air freights all of its European fashions into the United States. Honeywell increased its percentage of shipments by air from 10% in 1967 to 60% in 1970 (ref. 9), using air for international shipments of all computer parts and 80% of noncomputer parts. Motorola distributes replacement parts by air. Hoechst Pharmaceutical uses air distribution for replenishment of all its high-value drugs with a short shelf life. Searle air ships 30,000 to 60,000 pounds of drugs weekly to distributors throughout the United States. By changing from surface to air transportation, the Air Force was able to reduce its purchases of aircraft engines by almost a billion dollars.

Unfortunately, due to the natural reluctance of businesses to release proprietary information, factual data concerning savings from air transportation are usually not available. It appears, however, that an aggressive marketing approach for air cargo would lead air carriers to help companies identify cost reduction realizable by using air shipment. Personnel of one airline, for example, working with a clothing manufacturer found that the manufacturer could reduce annual distribution costs from $1,096,000 to $812,000. A drug manufacturer, conducting a 10-day test with another airline, discovered that distribution costs could be reduced by 43%. At least one aircraft company (Douglas) has developed an analysis model designed to help airlines and shippers identify the most economic transportation mode and to maximize reductions in total distribution costs (ref. 10). Other aircraft manufacturers have or are developing cargo cost simulation models.

Market analysts are hampered by lack of information concerning origins and destinations of commodities moving by various modes of transportation. CAB and DOT, recognizing the need for market data, have recently initiated a project to develop a system for collecting information on air cargo movements, including origin and destination data and data on costs of handling and transporting cargo. Such information will be helpful in policy decisions relative to air cargo systems improvement programs. It could provide a data base for aircraft manufacturers to use in designing cargo aircraft and in the sale of these aircraft. The airlines could use it in their cargo-marketing efforts.

The "peaking" effect precludes effective utilization of available air cargo capacity. Cargo is normally offered to carriers in the afternoon for next-morning delivery, so most cargo is flown at night. This makes for poor daytime utilization of all-cargo aircraft and of the belly compartments

of passenger aircraft. The Civil Aeronautics Board has been reluctant to approve off-peak or daytime incentive freight rates. Most proposals by the airlines to the CAB for such rates have included a provision that freight could be moved at night at the off-peak rate, on a space-available basis. The Board felt that approval of proposals with these provisions would present opportunities for discrimination. The problems of peaking might possibly be mitigated by multipurpose aircraft which could be used for short-haul passengers in the daytime and for cargo at night.

BELLY COMPARTMENT VERSUS ALL-CARGO AIRCRAFT

In fiscal year 1970, passenger aircraft handled 40.7% of the air cargo ton-miles (ref. 11). Cargo revenues (including certificated route and supplemental airline freight, express, U. S. and foreign mail, excess baggage, and charter revenues) account for more than 15% of airline transport revenue (ref. 12). It is apparent that freight carried in the bellies of passenger aircraft is a very important source of revenue for the airlines. Estimates of the percentage of the tonnage that will be moving in belly compartments vary from 10% in 1980 (ref. 2) to 34% in 1985.

The advantages of carrying cargo in passenger aircraft (as opposed to all-cargo aircraft) include greater frequency and service to more destinations. There are, however, weight, density, and size restrictions in belly compartments that do not exist in all-cargo aircraft. Also belly-cargo operations add to the congestion in passenger areas, many of which are already overcrowded. Additional handling contributes to loss and damage. There is always the danger that passenger flights will be delayed because of cargo, or that important cargo will be delayed to accommodate passenger schedules. More ground-support equipment is required to load a given amount of cargo in several passenger aircraft than in one all-cargo aircraft.

THE COSTS OF AIR SHIPMENT

The Civil Aeronautics Board prescribes a uniform system of accounts for scheduled air carriers and requires that detailed financial reports be filed with that agency. Costs incurred by the air freight industry would, thus, on the face of it, appear to be readily available. A fundamental problem arises in the interpretation of these data, however, because the airlines may allocate indirect operating costs between freight and passenger service or between all-cargo and combination aircraft service in any manner they see fit so long as the method of allocation is stated. The use of varying allocation methods and the resulting proliferation of arbitrary costs in the airline industry, particularly by combination carriers, have hindered efforts to make accurate determinations of the real costs of air freight service (ref. 13). Uniform cost accounting and reporting procedures are needed.

Since 1963, operating revenues per revenue ton-mile in domestic scheduled all-cargo service have been gradually declining (Table 3.6). However, air freight revenues per ton-mile (14.5 to 19.1¢) are still high compared to rail (1.34¢) and motor carriers (7.06¢).

Domestic operating expenses per revenue ton-mile have also been declining, but since 1963 expenses have exceeded revenues every year except 1966 and the first half of 1967. In contrast, international air cargo service has been profitable in every year since 1963, offsetting losses in domestic service. The difference between expenses per revenue ton-mile and expenses per available ton-mile (Table 3.6) shows that better utilization of available cargo space could cut costs by one-half.

To attract more freight, every effort should be made to reduce operating expenses. In 1969, direct operating costs (DOC) made up 58% of total operating expenses for all-cargo service (ref. 14). Large savings in DOC's may be expected as larger aircraft come into airline fleets. The

TABLE 3.6. OPERATING EXPENSE AND REVENUE PER TON–MILE, DOMESTIC SCHEDULED ALL–CARGO SERVICE

12 MONTHS ENDING	REVENUE PER REVENUE TON-MILE, CENTS		EXPENSE PER REVENUE TON-MILE, CENTS		EXPENSE PER AVAILABLE TON-MILE, CENTS	
	COMBINATION	ALL-CARGO	COMBINATION	ALL-CARGO	COMBINATION	ALL-CARGO
JUN 30, 1963	22.75	14.82	35.43	20.03	21.38	12.43
DEC 31, 1969	19.12	14.46	20.71	19.55	9.32	10.05

Source: Ref. 14.

DOC of a 50-ton payload commercial aircraft is approximately 3.22¢ per ton-mile. Douglas Aircraft Company estimates that with today's technology this could be reduced to 2.42¢ in a 100-ton aircraft and 2.18¢ in a 250-ton aircraft. Continuing improvements in technology will lower these costs even further.

The C-141 and the C-5A were designed as cargo aircraft for the Air Force, but incorporate features to meet unique military requirements not needed by commercial carriers. Operating costs are higher than they would be with a commercial cargo design. Instead of buying military cargo aircraft, commercial carriers have converted passenger aircraft to cargo service. They are not as efficient from a cargo-handling viewpoint as they would be had they been designed for freight. Uncompromised commercial cargo aircraft will probably be straight-in end-loading designed to carry standard modular containers. Significant weight savings will accrue when the aircraft design omits provisions for passenger comfort or safety. These savings will permit more payload for the aircraft.

As direct operating costs are reduced, indirect operating costs will assume greater importance. "Traffic servicing" accounted for approximately 43.5% of the indirect operating expenses of scheduled all-cargo service in 1969 (ref. 14). A more-or-less typical breakdown of traffic servicing costs is given in Table 3.7. Cargo handling costs cannot be isolated under the method of reporting traffic servicing costs currently prescribed by the CAB. Detailed information similar to that shown in Table 3.7 is needed from all airlines if meaningful cost analyses are to be conducted. Traffic servicing costs for all-cargo aircraft used by American Airlines are approximately $74 per originated ton of domestic cargo as compared with

TABLE 3.7. TRAFFIC SERVICING EXPENSES (A 1969 CASE)

SERVICE	COMBINATION AIRCRAFT, PERCENT	ALL-CARGO AIRCRAFT, PERCENT
LOADING AND UNLOADING	35.9	5.7
ACCOUNTING AND INFORMATION SERVICE	10.6	14.2
FREIGHT AGENTS	12.2	16.1
WAREHOUSING	24.6	47.3
GENERAL AND ADMINISTRATIVE	16.7	16.7
TOTAL	100.0	100.0

Source: Ref. 15.

$149 for combination passenger-cargo aircraft (ref. 15). Analysis of a domestic all-cargo operation in 1975 utilizing an uncompromised cargo aircraft, such as the Lockheed L-500, indicates that traffic servicing costs might be reduced to about $36 per ton.

Loading and unloading costs for end-loading aircraft will be substantially lower than they are for current side-loading aircraft. The cost reductions, however, are quite small compared to today's total traffic servicing costs. When the volume of air freight forecast for the 1980's and expected improvements in efficiency of the other activities that make up traffic servicing are taken into account, loading costs may become a more significant portion of traffic servicing costs. An airplane designed for cargo will permit greater efficiency in loading and thus offer significant cost savings for the future.

As the air freight market expands, larger aircraft will be required, the use of standard modular containers will increase (bringing improved stacking efficiency), and the volume of preconsolidated cargo will increase. These factors will improve the efficiency of cargo handling operations, and help reduce unit handling costs.

GROUND HANDLING AND DOCUMENTATION

Even though mechanized equipment is used to transport cargo from the terminal to the aircraft, handling of cargo on the ground is still primarily a manual operation. At best, terminal operations are semiautomated. Containerized or palletized loads are positioned in the aircraft and secured by hand; belly compartment loading is an inefficient, time-consuming, and costly manual operation, except where containers are used.

In general, each airline uses cargo handling equipment designed to its own specifications. Route structure, service schedules, degree of automation desired, and capital investment lead each airline to arrive at a different specification. In some cases, the airlines specify performance requirements; in other cases, manufacturers develop equipment based on their understanding of airline requirements. As a result, current cargo handling equipment is expensive, difficult to maintain, not standardized, and of limited interchangeability.

Documentation is a major problem – and a major cost generator. Each airline has its own commodity codes for statistical and rate-making purposes. The Department of Transportation has been encouraging all modes of transportation to adopt the same commodity codes. The airlines are now beginning to use electronic data processing systems for computerized control of cargo, providing positive control of shipments from origin to destination, reduction of paperwork, and speed-up of documentation. Standardization of codes is essential if the economies possible with computerized control are to be realized, particularly when a shipment is handled by more than one carrier between its origin and destination.

Customs clearance for cargo is available only during daytime hours (Monday through Friday), unless the consignee pays overtime charges. Shipments may thus be delayed as much as 16 hours on a week night and 64 hours on a weekend. The airlines must provide temporary warehouse space for the delayed cargo, contributing to high traffic servicing costs.

FACILITIES

The size of the U. S. all-cargo aircraft fleet may be expected to grow to about 505 in 1985, compared to about 100 in 1968. The fleet will include aircraft with much greater capacity than current aircraft (see Fig. 2.10 in the "Systems Status and Potential" section).

Many communities will be faced with the necessity of building new airports in the next few years because they will not be able to expand existing airports. They will have the options of building specialized airports, that is, all-passenger,

all-cargo, and general aviation airports, or additional combination airports. It may prove advisable to move major cargo facilities away from the airport, to one or more locations convenient to shippers. Generally, land for these facilities will be less expensive than land at airports, and the move may postpone saturation.

Consolidation of cargo at off-airport locations would reduce congestion on surface transportation routes to and from the airports. The average load on trucks carrying cargo to O'Hare Airport in Chicago during November 1969 was 1230 pounds (ref. 16). If the average load stays at this level, by 1985 more than 2670 trucks an hour will be arriving at O'Hare during the four peak hours each day. If the average load can be increased to 12,300 pounds by off-airport consolidation, the peak-hour number of trucks will remain at about the current level.

Combination airports could better utilize runways and other facilities than specialized airports because most passengers fly in the daytime and most cargo is flown at night. Communications and ground-transportation costs would be higher with specialized airports because of the requirement to move cargo between passenger-aircraft belly compartments and all-cargo aircraft. Specialized airports would be preferable from a cost-accounting viewpoint. Land costs for all-cargo airports would probably be less per acre because they could be built farther from the cities. The total acreage required for combination airports, however, should be less than for specialized airports because common facilities would be used more efficiently.

On balance, combination airports, with the maximum use of off-airport facilities, appear to be preferable to specialized airports, regardless of the levels of passenger and cargo traffic. However, all of the alternatives should be carefully considered before a decision is made in any specific community.

CONTAINERIZATION

The modular container is one of the important transportation developments of this century. Small shipments are now being consolidated in containers for shipment by air, rail, truck, and water. The use of containers minimizes costs of packaging, handling, damage, pilferage, terminal space, and insurance. Container ships first appeared in international trade in 1966; by 1970 about 125,000 containers were being used by U. S. maritime carriers. Despite the progress made, much remains to be done. The greatest need is for an intermodal container – interchangeable among air, motor, and rail carriers. This development could be as important to the national economy as establishing a standard rail gage.

Research and development is needed to achieve a container light enough for air transportation while still having the strength required for handling in all transport modes except ships; it does not seem feasible at this point in time to build an intermodal container to meet maritime handling requirements. The development of an intermodal container system would be to the advantage of U. S. carriers and shippers alike since it would permit door-to-door service in one container. Standardization of container sizes, shapes, and restraining devices is needed. Lack of standardization may not prevent interchange of containers, but it increases operating, maintenance, and initial investment costs.

There will be a need for a container central control office, employing the latest automatic data processing systems, to track the location of containers and associated equipment in the U. S. and abroad. The office would provide information and administrative support to shippers, consignees, intermodal carriers, and freight forwarders, both domestic and international. It would assist in spotting imbalances in the container inventory, identifying shortages, and highlighting excessive tie-ups. This concept is already used by the railroad industry in the interchange, pooling, and cost allocation of rail cars.

GOVERNMENT POLICIES

Transportation problems today are vastly different from those in the early stages of the country's growth when regulation was first imposed. Shippers now have a wide range of choice in modes and routes. The notion that transportation is a natural monopoly is no longer relevant (except for certain commodities in limited and well-defined markets). It is increasingly clear that the number and variety of transportation alternatives available today have made comprehensive and complete regulation administratively infeasible as well as economically undesirable. The central and primary objective of an updated regulatory program should be to establish criteria emphasizing the achievement of certain broad standards of performance rather than to prescribe precise specifications for particular firms or industries.

Companies have been denied certificates to provide air cargo service because they could not prove that the service was required as a matter of public convenience and necessity. In normal business, entry or withdrawal from a market is based on a reasonable relationship to the existing business of the firm and on a reasonable relationship to an existing and prospective market. An applicant should be required to state his expectations in specific terms, meeting reasonable quantitative standards. Approval of an application should depend on performance in a test period to determine if projected standards were met. Shippers would benefit from this relaxed form of entry control because more service would be available. Competition would be intensified and freight rates could be expected to drop.

Carriers should be able to provide door-to-door service. Only motor carriers and freight forwarders can provide this service today because the transportation regulatory agencies do not permit multimodal ownership. There would be many advantages to the shipper in multimodal ownership. The division of responsibility for the quality of service that exists today would disappear. In-transit delays should be reduced. Reimbursement for loss and damage would be easier to collect. Carrier operating expenses would be lowered by reducing the amount of overhead and paperwork.

The biggest problem facing air cargo transportation is the lack of a total systems approach. There is need to coordinate the efforts of governments, airlines, aircraft manufacturers, shippers, airport operators, and interfacing modes of transportation. The technological, economic, regulatory, and marketing aspects of air cargo must be integrated if the inherent advantages of this transport mode are to be fully realized. One office should be designated within the Federal Government to perform this coordination and integration.

CONCLUSIONS AND RECOMMENDATIONS

As discussed in the section on air vehicles, little new technology will be required for new cargo aircraft, and no Government support of R&D for cargo aircraft seems warranted.

An office should be designated within the Federal Government to coordinate actions on the following matters:

- Review of regulatory policies of the Federal Government concerning rates, certification of new carriers, and multimodal ownership in order to determine the impact on costs, marketing, innovation, and growth of air cargo.
- Standardization in accounting procedures, documentation, and data reporting.
- Improvement of cargo handling equipment and facilities. Major problems are evident in containerization, materials handling equipment, cargo terminals, and transfer to other modes of transportation.
- Provision of current and forecast cargo movement data, to permit more effective trade-off studies and marketing efforts.

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GENERAL AVIATION

General aviation includes all civil flying except that of the public air carriers. It covers a broad spectrum, including personal travel, pleasure flying, and private business and corporate flying. It includes instructional flying and special-purpose missions, such as firefighting, aerial mapping and photography, powerline and pipeline patrol, agricultural crop control, and highway traffic observation. Air taxi and commuter airlines have evolved from general aviation, and are treated in the "Commercial Passenger Service" section of this report (except for the safety aspect, which is included in this section).

General aviation aircraft range from small, single-place piston aircraft to very large jet transports and rotorcraft. Avionics equipment used in these aircraft ranges from simple navigation and communications transceivers for visual flight rule (VFR) flying to complex systems, including weather radar, autopilot, flight director display and approach coupler for instrument flight rule (IFR) capability and Category II landing operations.

The primary focus of this section is on the personal operators. The service they provide is not offered for hire to the general public, but is primarily for pleasure or is incidental to business activity. The personal category represents the largest component of general aviation activity in terms of number of vehicles and number of pilots (Table 3.8 and ref. 1). More than 70,000 of the 130,806 aircraft in the general aviation category are private aircraft.

The general aviation inventory represents 98% of the U. S. civil aviation fleet. It flies 1.6 times as many plane miles and 4.3 times as many hours as the certificated route air carriers. Moreover, although general aviation generates less than 10% of the total domestic air passenger-miles, it utilizes 20 times as many airports as domestic air carriers (refs. 1, 2).

Based on an expected average growth rate of 5.3% per year, by 1985 approximately 287,000 general aviation aircraft, flying approximately 57 million hours, must be anticipated (Figs. 3.22, 3.23). Private operators (personal, instructional, and other categories shown in Table 3.8 and

TABLE 3.8. COMPARISON OF GENERAL AVIATION WITH U. S. CERTIFICATED ROUTE AIR CARRIERS, 1969

CATEGORY	NUMBER OF AIRCRAFT, DEC 31, 1969	HOURS FLOWN, MILLIONS	MILES FLOWN, MILLIONS	PASSENGER-MILES, MILLIONS
PERSONAL	70,500	6.0	829.0	1,907
BUSINESS AND EXECUTIVE	24,388	7.1	1,426.0	4,768
COMMERCIAL	11,832	4.9	722.9	1,770
AIR TAXI[a]	5,642	2.5	–	–
AERIAL APPLICATION	5,788	1.4	–	–
INDUSTRIAL/SPECIAL	402	0.9	–	–
INSTRUCTIONAL	15,655	7.0	910.3	1,274
OTHER	8,431	0.3	38.3	96
TOTAL GENERAL AVIATION	130,806	25.4	3,926.5	9,815
U.S. AIR CARRIERS, SCHEDULED SERVICE	2,690[b]	5.9	2,400	125,400

[a]*Nonscheduled air taxis only; scheduled air taxis (commuter airlines) are excluded.*

[b]*Aircraft in use.*

Source: Refs. 3, 4.

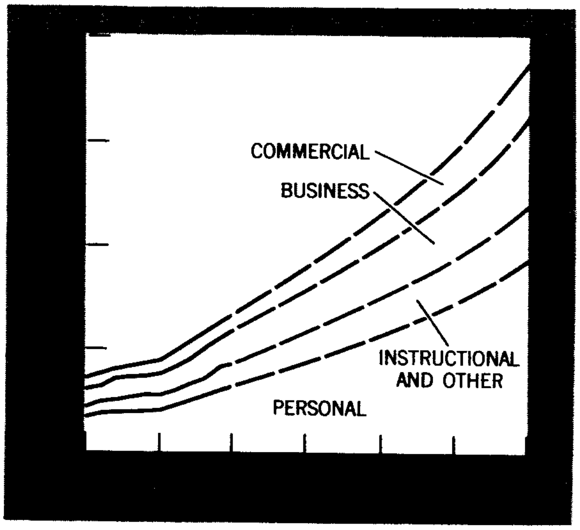

Figure 3.22. Actual and projected number of general aviation aircraft, by use.

Figs. 3.22 and 3.23) will account for about 65% of the general aviation inventory and 50% of the hours flown. Such large numbers of private planes in the air system, operated generally by pilots less skilled than commercial pilots, will pose a substantial load on air traffic control and airports in the future. This load must be handled with maximum possible safety.

COSTS

Table 3.9 shows the estimated total cost per mile per person for auto, scheduled air carrier, and personal aircraft.

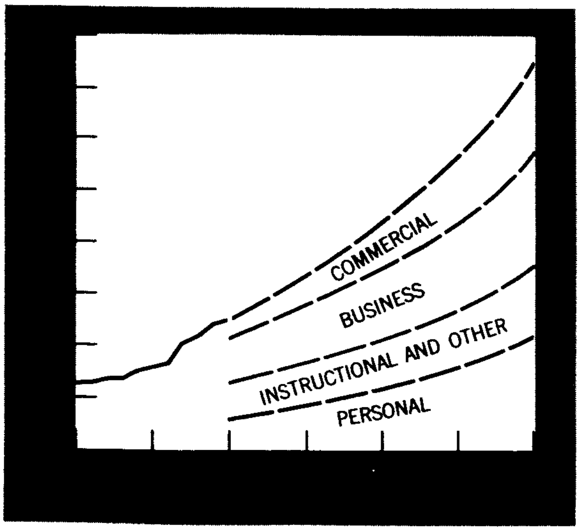

Figure 3.23. Actual and projected number of general aviation flight hours, by use.

TABLE 3.9. COSTS PER MILE PER PERSON (CENTS)

MODE	ONE PERSON	FOUR-PERSON FAMILY	SIX-PERSON FAMILY
PRIVATE AUTO	12.6	3.2	2.1
SCHEDULED AIR CARRIER	5.6	4.9	4.5
PERSONAL AIRCRAFT[a]	17.3	4.3	3.3

[a]*Predicated on substantial usage of 150 hours per year.*

Travel cost for a single individual is substantially less by scheduled air carrier than by the other two alternatives. Personal air carriage is the most expensive. For a four-person family, however, the situation changes completely. The costs for the private auto and the personal plane fall below the scheduled air carrier.

The personal automobile provides a family greater flexibility than the personal aircraft. Also, a personal aircraft calls for a substantial capital investment. The initial cost of a personal aircraft will run at least four to five times that of a car. Consequently, unless there is a substantial improvement in the operating and investment cost, and in utilization of personal aircraft, the market will continue to be limited.

PROBLEMS

Federal Government actions "to ensure safety of operations" have a direct bearing on the cost and usefulness of private aviation. These include:

- Certification of aircraft and equipment
- Certification of pilots and training instructors
- Specification of training curricula

- Establishment and operation of the Nation's air traffic control system
- Aviation weather service and flight-service stations
- Aviation communications service
- Airport investment decision through the Airport and Airway Development Act (ref. 5).

The way the Government exercises its authority in these areas directly affects the cost of service and the safety of all general aviation operations.

Safety

Safety is of particular concern to private aviation. Although the rate of general aviation fatalities has decreased from 40 fatal accidents per million hours flown in 1955 to less than 30 in 1969 (Fig. 3.24), the *number* of fatalities has continued to increase as a result of the large increase in the number of operations (Fig. 3.25 and ref. 6).

In 1969 there were 1388 general aviation fatalities. (In 1970 there were about 100 fewer fatalities than in 1969.) If accidents continue to occur at the same rate, approximately 4000 fatalities must be expected in 1980 (ref. 2).

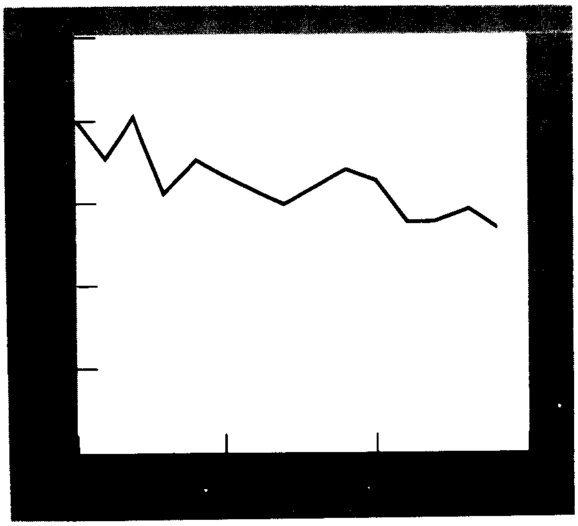

Figure 3.24. General aviation fatal accident rate, 15 years.
Source: Ref. 6.

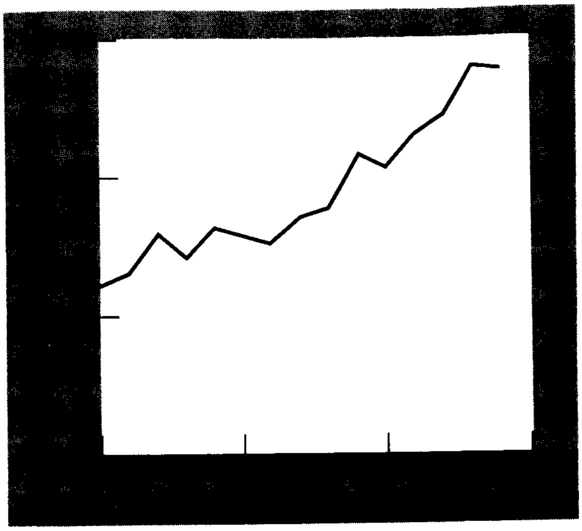

Figure 3.25. Number of annual general aviation fatalities.
Source: Ref. 6.

Data from the National Safety Council show that the general aviation fatality rate far exceeds the rate for other transport modes (see Table 3.10).

It may be seen that the risk is 7.7 times higher in general aviation than in automobile travel, and 139 times higher than in scheduled domestic airline travel. As shown in Table 3.11, however, in terms of public accidents, general aviation ranks *fourth* (ref. 7). In terms of *all*

TABLE 3.10. FATALITIES AND RATES (PER 100 MILLION PASSENGER MILES) 1969

TRANSPORT MODE	NUMBER OF FATALITIES[a]	FATALITY RATE
AUTOS AND TAXIS	37,200	2.30
BUSES	150	0.22
RAILROAD PASSENGER TRAINS	9	0.07
AIR: SCHEDULED DOMESTIC	131	0.13
NONSCHEDULED DOMESTIC	6	–
INTERNATIONAL	0	0
GENERAL AVIATION	1,388	18.00

[a]*Includes passengers only, except for autos, where the driver is considered a passenger.*
Source: Ref. 7.

TABLE 3.11. PUBLIC ACCIDENTAL DEATHS, 1969[a]

CATEGORY (IN RANK ORDER)	NUMBER
FALLS	5,500
DROWNING	4,800
ALL OTHER PUBLIC	5,500
AIR TRANSPORT:	1,400[b]
GENERAL AVIATION	1,388[c]
CERTIFICATED CARRIERS	158[c]
FIREARMS	1,100
WATER TRANSPORT	1,100

[a]*Includes deaths in public places or places used in a public way, not involving motor vehicles. Excludes deaths in the course of employment.*
[b]*Does not include crew.*
[c]*Includes crew.*
Source: Ref. 7.

TABLE 3.12. ALL ACCIDENTAL DEATHS (PUBLIC AND NONPUBLIC), 1969

CATEGORY (IN RANK ORDER)	NUMBER
MOTOR VEHICLES	56,400[a]
FALLS	19,000
DROWNING	7,300
FIRES, BURNS, ETC.	7,100
FIREARMS	2,600
POISONING (SOLIDS, LIQUIDS)	2,500
MACHINERY	2,000
POISONING (GASES, VAPORS)	1,700
AIR TRANSPORT:	1,400[b]
GENERAL AVIATION	1,388[c]
CERTIFICATED CARRIERS	158[c]

[a]*Includes pedestrians and others killed by motor vehicles.*
[b]*Does not include crew.*
[c]*Includes crew.*
Source: Ref. 7.

accidental deaths, general aviation ranks *ninth* (see Table 3.12 and ref. 7).

Tabulations from the National Safety Council show that general aviation travel is a high-risk form of transportation when fatalities are compared on an *exposure* basis (in terms of passenger-miles) (Table 3.10). However, a broadened perspective is obtained when the number of general aviation fatalities is compared to the number of other public and private accidental deaths. Fewer people die from general aviation accidents because a relatively small portion of the population engages in private flying. It is to be expected then that the allocation of *public funds* to improve the safety of general aviation operations would receive a proportionately lower priority than other areas which are the source of a number of accidental deaths – such as motor vehicles, firearms, and poisoning.

Expenditure of public funds for maintaining the safety of the *airspace* is an entirely different issue, because the Federal Government has had a long-standing role in assuring safety of the airways for those who use *public* air transportation. To assure the safety of the air carriers, it is necessary for the Government to control and provide air traffic services to the private air sector as well.

The problem of safety in general aviation has two basic dimensions:

- The aircraft and its subsystems
- The airman's proficiency and experience

The Aircraft and Its Subsystems. General aviation accidents and fatalities are occurring at disturbingly high rates. The question then is: Have technology and regulation been adequately applied to minimize this problem?

Although the aerospace industry has been noted for technological progress and innovation, the technology incorporated in most personal aircraft is quite old. Today's certificated general aviation aircraft meet Federal Air Regulations requirements for airworthiness and safety. However, the type certificates for one-third of all private aviation aircraft produced in the first nine months of 1970 were issued 12 or more years ago. Table 3.13 shows the age of approved type certificate applicable to airplanes recently produced by a general aviation manufacturer.

TABLE 3.13. TYPE CERTIFICATE AGE FOR TYPICAL AIRCRAFT PRODUCED FROM JAN–SEPT 1970

YEARS SINCE CERTIFICATE ISSUED	PERCENT	CUMULATIVE PERCENT
LESS THAN 6	5.5	5.5
6-10	18.0	23.5
11-15	70.0	93.5
OVER 15	6.5	100.0

Much untapped technology is already available to improve vehicle safety; this suggests that something has discouraged change or innovation by the industry. For example, the costs associated with the certification process are high; it may be that they have served as a deterrent, especially since they must be passed along to the customer in the form of increased prices. Certification would appear to be a definite deterrent to radical changes (such as use of plastics in structures) since standards are set up on the basis of current practice and are not easily changed.

Another view is that the nature of the market is responsible for innovation not being as rapid as it might have been in general aviation aircraft. The product is costly and the market is very price-sensitive. The cost of R&D applied to a small production run can become a significant addition to the selling price and could act as a deterrent to acceptance by the purchasing public. Consequently, general aviation manufacturers have been motivated to "give the public what it wants," based on years of successfully gaging the needs of their market. Even though the aviation community possesses technologies which could improve general aviation aircraft, market acceptance could likely be low because of the added cost.

As the number of users of private aircraft increases, it is probable that fewer pilots will be "dedicated" to aviation. Flying will become more of a means to an end rather than an end in itself. Private aircraft operation should therefore become as simple and easy as driving an automobile. Aircraft that require elaborate "preflight" checks for safe operations will find decreasing acceptance – or will produce higher accident rates. Most people will want to simply check to see that it is all there (pilots call this "kicking the tires"), climb in, turn the key, and drive off.

Aircraft designers must make every effort to make safe operation less dependent on the skill and expertise of the pilot. Aircraft of the present generation have adequate stability under normal conditions but the demands placed on the pilot in turbulence or under conditions of poor visibility sometimes prove too great for him and an accident results. Also, despite the best efforts of instructors, a few pilots still fly aircraft into trees, mountains, and each other. There is need for more crashworthy vehicles to protect occupants in the event of a crash. Current certification processes on aircraft need reappraisal to promote and foster technological advance in the private aviation industry. Too often, certification minimums, as written, tend to become design standards.

The Airman's Proficiency and Experience. The proficiency of the general aviation pilot ranges from that of the inexperienced student to an airline transport-rated pilot. Training for private flying has changed little over the past 60 years. Once over the hurdle of the first solo and the private flight test, in general the individual pilot has only his experience as an instructor. Programs for proficiency checks or retesting are few and purely voluntary. There is no requirement for updating on aircraft communications, navigation, air traffic control procedures, or even basic aircraft operations. The approach is essentially: once licensed, always licensed. In recent years, a substantial amount of pilot training beyond the private pilot certificate was paid for by the Federal Government through programs under the Veterans Administration. As a result of this subsidy, the Federal Government, in effect, extended the amount of training undertaken. The experience and proficiency of the present pilot population is somewhat higher as a consequence than otherwise would have been the case.

The major causes of fatal and serious injury as a result of pilot error are:

- Failure to obtain and maintain airspeed
- Continuation of VFR flight into adverse weather conditions
- Inadequate preflight preparation and/or planning
- Spatial disorientation.

To reduce the accident rate of the private pilot, R&D in the following areas should be expanded:

- Training curricula and training aids
- Psychology of flight
- Low-cost proficiency evaluation and updating program, using simulators
- Safety awareness on the part of the private pilot
- Standardization of instrumentation.

Although the basic functions of piloting in good weather become instinctive – much like those of riding a bicycle (i.e., once learned, always remembered) – a safe level of pilot proficiency requires substantial practice. The high cost of flying, however, tends to limit practice. Simulators could provide less expensive proficiency training and maintenance than actual flight.

Air Traffic Control

Air traffic control systems are intimately related to the nature of the aircraft and its subsystems, and to air crew proficiency. Consequently, the systems selected and the regulations pertaining to their use will have considerable impact on the cost of private flying. It is estimated that the annual number of IFR itinerant flights will grow from 7 million in 1968 to 21 million in 1980. The proportion of these which are general aviation will change from 17% in 1968 to 40% in 1980 (ref. 2). This tremendous increase in load on the air traffic system may sharply limit the use of air transport in some parts of the country unless realistic long-range plans supported by adequate R&D programs are undertaken.

As severe congestion builds around busy terminal areas, the traditional "first come, first served" of the present air traffic system will have to be abandoned. The present approach for allotting time and space is workable only if there is excess capacity in the system or if users are willing to accept substantial delays. The problem is compounded because the number of alternate routes is limited and airborne delays cannot be too long (not unlike an automobile in heavy traffic). Increasing demands on the traffic system will require some sort of rationing and priority scheduling. Increasing the capacity of the current system may postpone rationing and priorities, but the cost to the users (in terms of equipment, reliever airports, etc.) may be substantial.

At certain times and places in the current system, a "slot" in the air traffic system is not free. Queues for takeoff and landing as well as delays for traffic clearance are the price that must be paid for using the system at that place and at that time. Alternatively, the cost may be distributed among users by means of a rationing/priorities scheme (as now employed at Washington National, Kennedy, La Guardia, and Chicago O'Hare). With this approach, the delays or postponements (costs) are arbitrarily allocated to some users.

Another approach would be to structure airways and airport user fees to reflect the level of demand at various places and points in time. The concept of charging the user a higher price for "prime" time is not new. It has been employed in radio and television for 40 years.

The present air traffic control system has two basic modes of operation: operation under positive control (essentially operations under instrument flight rules); and uncontrolled operation (essentially operations under visual flight rules). In the former, the maintenance of aircraft separation is the joint responsibility of the air traffic controller and pilot. In the latter, aircraft separation is solely the responsibility of the pilot (see and be seen). Increasing traffic density and the

mixing of positively controlled (IFR) and uncontrolled (VFR) traffic in congested terminal areas requires both the pilot's eyes and the controller's radar to maintain traffic separation.

The number of in-flight collisions of general aviation aircraft has grown by a factor of three over the past five years. In 1969 there were 45 collisions. Three of these involved an air carrier. In virtually all aircraft collisions, at least one, and frequently both, participants were operating under visual flight rules. The possibility of more midair collisions and the expected heavier burdens on the air traffic controller suggest the need for some form of cooperative proximity-warning indication or collision-avoidance system that could be carried by all users of the airspace – general aviation, military, and airlines alike.

Another problem in general aviation safety is navigation. Many general aviation operations take place in areas where no signal coverage is available from the VOR-DME navigation system. A low-cost navigation aid using very low frequency has the potential of satisfying this need.

The following R&D is recommended:

- Experimentation with alternative pricing or rationing policies to be used with any proposed air traffic control system
- As a part of the development of a new-generation air traffic control system, the parallel development and refinement of a practicable proximity-warning system to permit expanded and safer "uncontrolled" aircraft operations.

Airports

Present-day congestion in the terminal airspace and on the airport is largely a product of the particular pricing mechanism used. A full-cost pricing system which recognizes that the demand for service varies with time of day would go a great distance toward relieving congestion at terminal airports. Use of a "market mechanism" for pricing airport services would also ease the problems of future airport investment decisions (i.e., decisions such as where, when, and in what configuration).

In such an environment a private aviation user who was appropriately equipped to cooperate with the system and willing to pay the price of admission could be assured access to major terminals. On the other hand, if he were unwilling to pay the cost of using a major terminal, he could use a "reliever" facility at a lower cost.

Many general aviation pilots prefer not to use the major airports because of the added cost of airborne equipment, their inexperience, or their uneasiness over operating in such a complex environment. Consequently, the private pilot generally welcomes an airport dedicated primarily to his use. Increases in land values and other urban pressures, however, have resulted in greatly increased costs of airports in major urban areas. (A number of these airports, in fact, have been closed in recent years.) As a result, users of general aviation aircraft in large urban areas incur either higher costs or time-consuming ground transport between airport and city center, thus reducing the utility of general aviation for business and personal transportation purposes.

The Airport and Airway Development Act of 1970 (ref. 5) provides for payment of user charges by the general aviation public. It is anticipated that $796 million will be collected from general aviation from 1971 through 1980. General aviation will receive funds from the Trust Fund in three allocations. It will receive $30 million per year solely for general aviation airfield development. It will share $180 million per year for development of air carrier fields and reliever airports. The third allocation will come from sharing the discretionary fund.

The National Aviation System Plan includes a need for 747 new or converted general aviation airports to meet the 1980 demand. Fifty-eight of them will be needed in high-density areas, 100 in

medium-density areas, and 589 in low-density areas (ref. 8). Although there will be substantially more Federal funds available for the development of general aviation airports, the funds must be matched by local authorities, who may be hard-pressed in the future to raise funds because of mounting pressures to substantially reduce noise and air pollution. Failure to take positive action in these areas may make it very difficult to develop enough general aviation airports to manage the expected growth.

BENEFITS

The general aviation market has had a positive influence on the national economy. Total contribution to GNP by the general aviation industry in 1969 was about $3 billion. Based on present growth, it is anticipated that this will grow to $7 billion by 1980 (ref. 9).

General aviation has also had a positive benefit on regional development, particularly in rural areas. Studies in Ohio, Minnesota, and other areas have shown an impressive influence by general aviation on the areas it serves.

GOVERNMENT INVOLVEMENT

General aviation R&D efforts need to be expanded in the area of vehicle safety and utility and on airways control and safety. Because only a relatively small percentage of the public engages in private flying, R&D to improve the utility of vehicles or propulsion units should be performed by the manufacturer. Because the Government has an obligation to assure the safety of the airspace for public transportation, it is appropriate for the Government to engage in air traffic control R&D to the degree necessary to assure the expeditious and safe movement and control of all aircraft, whatever the type, since safety cannot be assured in the airspace without adequate measures for all vehicles in the system.

It is therefore evident that the role of the Federal Government should continue to be that of a regulator and promoter of safety in airways, vehicle certification, and pilot proficiency. It may be necessary for the Government to engage in some R&D efforts to gain a better understanding of the nature of these problems and establish reasonable limits of operation.

CONCLUSIONS AND RECOMMENDATIONS

- To improve the utility of general aviation aircraft and to make them safer for the average pilot, R&D is required on flying and handling qualities and on crashworthiness. These efforts should be pursued by the private sector.
- Some technology which would permit the design of safer and simpler general aviation aircraft is already available to the aviation community, and thus the R&D programs required are not extensive. However, manufacturers of general aviation products have been slow in incorporating new technology, probably because the market is extremely price-sensitive. New mechanisms need to be explored by the Federal Government to encourage the use of new technology which will improve the safety of general aviation.
- R&D studies should be initiated to develop improved training curricula and training aids for the private pilot. In-depth analyses of the psychology of flight and methods to develop a low-cost proficiency evaluation are also needed.
- Airspace in congested areas should be looked upon as a commodity with value. It is recommended that demonstration experiments be expanded to structure landing fees to reflect the local demand at different times of the day. The experiments should cover a range of fees so that accurate profiles of demand versus time versus cost are obtained.
- Today, 40,000 to 50,000 aircraft are equipped with beacon transponders, and

more general aviation pilots are purchasing them as the complexity of traffic control increases. A regulation covering beacon transponders is believed essential so that the entire system can be further automated and the costly primary radar system eventually retired. It is recommended, therefore, that a four-step program, leading to a fully cooperative air traffic control system, be initiated. The Federal Government should perform the R&D necessary to develop the standards required of the avionics by year end 1972. Installation of the transponders should occur on the following time scale:

1973 (year end)	– all newly manufactured aircraft
1980	– all users flying in the 30 primary hub regions
1985	– all users in the system

(Certain special categories of general aviation aircraft such as crop dusters could be exempted.)

- Proximity-warning indicators will be essential elements as air traffic grows and the probability of midair collisions increases. Research on promising concepts for such devices should be emphasized, with a view to arriving as soon as possible at the development and refinement of an operational proximity warning system.
- Because of the broad spectrum of pilot proficiency in general aviation flying, it is recommended that the displays of all general aviation instruments be standardized to help promote safety, in much the same way the automobile gearshift was standardized for safety reasons. Avionics manufacturers should have complete freedom (within the limits of instrument performance requirements) in the design of their instruments so long as the readouts comply with standards. The Government can initiate this change through certification procedures and low-cost Government/industry joint efforts to develop standards.
- The cost of type certification may also inhibit innovation. Certification may not be a barrier to companies with established products but the innovator may experience penalties since certification is based largely on established practices. Deviations from established practices can be costly and time consuming, encouraging manufacturers to make only modest changes in their products. Current certification processes should be reappraised in order to promote and foster technological advance in the general aviation industry.
- A more effective and scientific method for determining causes of accidents and instituting corrective action must be developed. Currently there is not an effective scientific, closed-loop system to assure that such needed action is implemented. The method should include improved safety information storage and retrieval processes and emphasize investigation plus corrective action.

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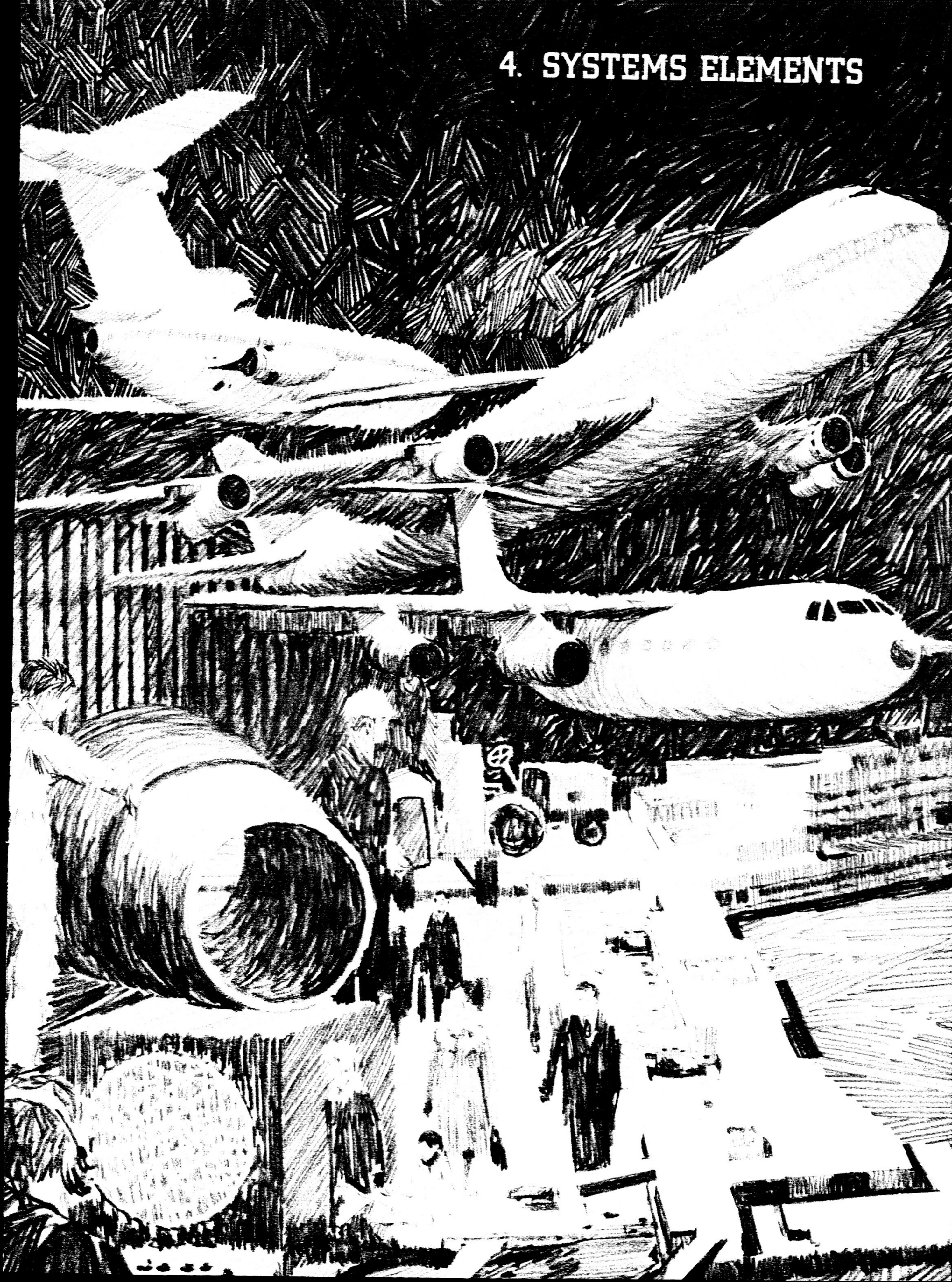
4. SYSTEMS ELEMENTS



Systems Elements

AIR VEHICLES

INTRODUCTION

As with most transportation systems during their formative years, the growth of air transport has been paced by the development of new, improved vehicles (Fig. 4.1). The air transport industry is now facing a number of problems, however, that can be solved only by system approaches that consider all elements of the air transport system – air vehicles, air traffic control system, airports, and complementary ground transportation. The importance of maintaining a continuous R&D effort cannot be overemphasized. Neither can the start of new research be delayed if U. S. transport aircraft of the 1980's are to be the world's safest and most economical. Target objectives should be: (1) reducing adverse effects of noise and atmospheric pollution; (2) increasing system capabilities and services; (3) improving operating economics; and (4) improving safety. Concerted action by Government and industry is essential to progress in these areas.

If air transportation is to continue to flourish, new solutions must be found to the problems that now inhibit progress. The Government industry partnership in R&D that has produced such fruitful results in the past must continue.

Economical aircraft for both military and civil uses have been made possible primarily through significant improvements in propulsion systems. The jet engine became a feasible propulsion system during the late 1930's and early 1940's. An active R&D program during the next 20 years (including application to military vehicles) made possible the "jet age," inaugurated in the United States in 1958.

Propulsion systems are expected to continue to pace new aircraft developments of the near future. A broad base of innovative propulsion research (including machines, fuels, and lubricants) is essential to generate the technology required if the U. S. is to maintain the lead it enjoys in the highly competitive foreign markets.

The swept wing is another example. A few thousand dollars spent in the early 1940's to evaluate the wing's benefits resulted in a well-rounded research program in the 1940's and 1950's. Subsequently, both military and commercial jet airplanes flew faster and more economically than

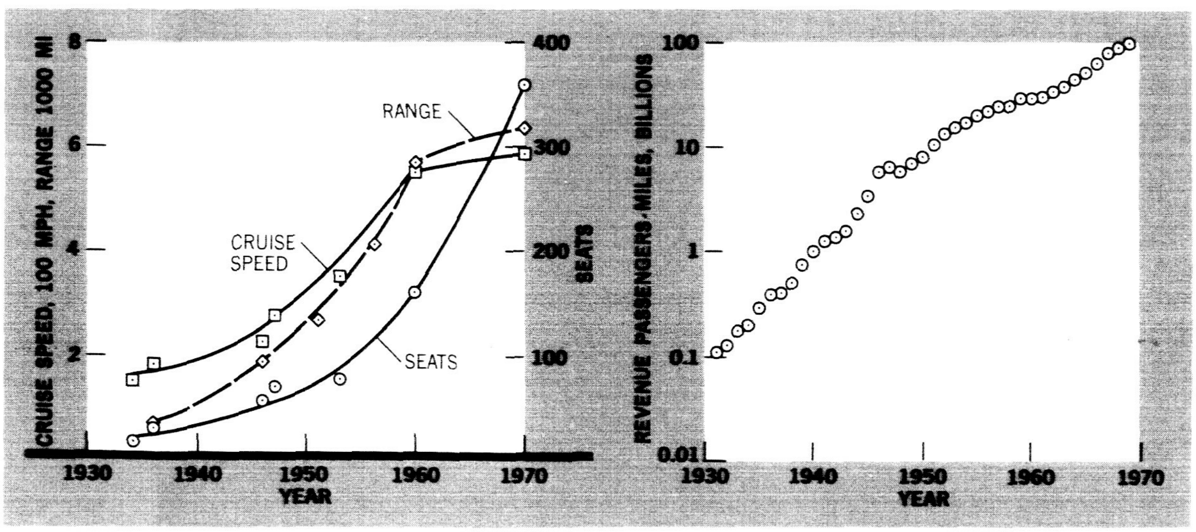


Figure 4.1. Growth in selected aircraft characteristics and U.S. domestic revenue passenger-miles. *Source: Refs. 1, 2, 3.*

their propeller-driven counterparts. The return to both the military and the traveling public from R&D expenditures paid off.

RESEARCH AND DEVELOPMENT REQUIREMENTS FOR SPECIFIC MISSIONS

General Aviation Aircraft

To many people, the Piper Cub (Fig. 4.2), produced by the thousands before, during, and for a short time after World War II, is still the image of general aviation. The Piper Cub, however, is no longer representative of general aviation. Today, general aviation aircraft range from fast, comfortable, single-engine propeller airplanes to large, high-performance machines, such as the four-engine Lockheed Jet Star.

Figure 4.2. Piper J–3 Cub.

General aviation aircraft in the past have been designed according to engineering and technology developed in support of aircraft for other purposes. Relatively little research has been directed specifically toward general aviation aircraft. Some problems not directly related to the air vehicle itself need study to increase the safety and utility of the aircraft in the hands of the nonprofessional pilot. Because large numbers of such aircraft will be in service in the 1980's, and because they will use the same airspace as commercial carriers (near airports particularly), R&D is needed to assure that these aircraft can use technology developed for more sophisticated civil and military aircraft. R&D is also needed to assure that propulsion systems – either propeller or jet – have satisfactory noise and pollution characteristics. However, improving the utility of general aviation aircraft does not appear to be of sufficient interest to the general public to involve the Government. The Government should continue its role in establishing safety and operating criteria and in improving air traffic control for general aviation aircraft.

Short Haul

Vehicles for the less dense short-haul market will probably be conventional takeoff and landing (CTOL) aircraft with low operating costs at short ranges. Technology in aerodynamics, high-lift systems, avionics, and propulsion systems is available for designing such aircraft. R&D should be directed toward better structures and materials (including fail-safe structures) to provide safe, efficient aircraft at minimum cost, since a large portion of the operating cost depends on vehicle purchase price.

A STOL or VTOL aircraft can probably best satisfy the needs of more dense short-haul markets. Considerable R&D will be required to make these aircraft economically viable and comfortable, with noise and pollution levels low enough to allow operation near densely populated areas.

One of the best STOL aircraft ever developed was the Ford Tri-Motor A26 (Fig. 4.3). It had excellent short-field performance. It also had very poor cruise performance and a rough rocky ride, most unpleasant for the passengers. The Tri-Motor achieved its good STOL performance through low wing loading and high power-to-weight ratio. Most of today's STOL aircraft are simply conventional aircraft that also use low wing loading, high power-to-weight ratio, and moderately powerful flaps to achieve STOL performance. To some degree, these aircraft suffer from the same deficiencies as the Ford Tri-Motor.

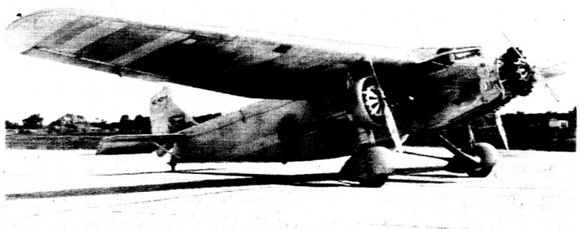


Figure 4.3. Ford Tri-Motor.

If short-field takeoff and landing performance is to be achieved with acceptable cruise performance and good ride qualities, the use of power-generated lift will be necessary. STOL operations with large propeller-powered, deflected slipstream aircraft, such as the McDonnell Douglas Model 188, may increase during the next few years, but development of large jet-powered STOL transports is needed. Their higher cruise speed capability and improved ride qualities (resulting from the high wing loadings of jet-powered aircraft) would make possible better service for the user and an economically sounder operation for the airlines.

The three most promising ways of obtaining jet lift are shown in Figures 4.4, 4.5, and 4.6.

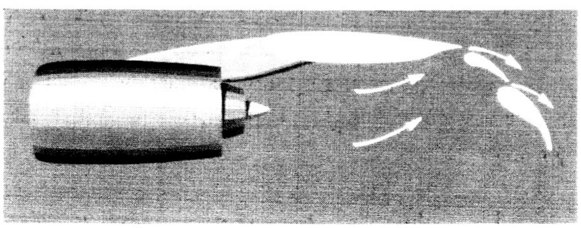


Figure 4.4. External-flow jet flap.

In the externally blown flap concept (Fig. 4.4), the jet engines are so located that their exhaust blows over a large flap system, increasing lift during takeoff and landing. In the internally blown flap concept (Fig. 4.5), all or part of the fan airstream passes through internal wing ducting and is blown directly over the flap surfaces or

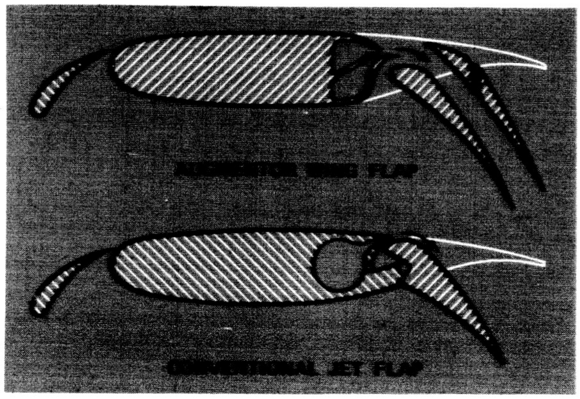


Figure 4.5. Internally blown jet flaps.

between a two-piece flap (augmentor wing) to achieve higher lift. With the lift-fan concept (Fig. 4.6), direct-lift fans are deployed only during takeoff and landing.

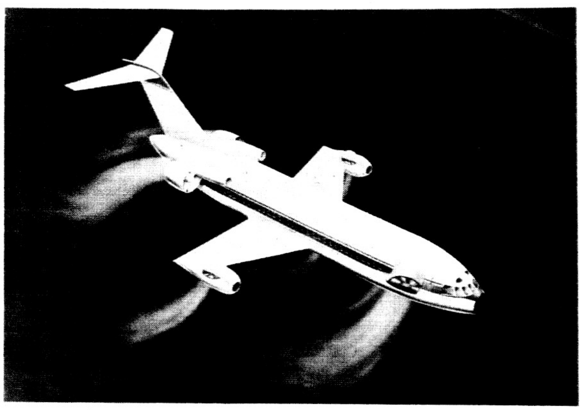


Figure 4.6. Direct lift transport.

Modified CTOL subsonic aircraft engines will undoubtedly power the first generation of jet STOL vehicles. The accompanying compromises in engine thrust-to-weight ratio, bypass ratio, and noise will, however, mean compromises in performance. Propulsion systems must be tailored to STOL aircraft. Aerodynamic and propulsion R&D must, therefore, be concentrated on efficient jet-lift and propulsion systems with acceptable noise and pollution characteristics. Another area requiring R&D is satisfactory control and performance in the event of engine failure, which could be accompanied by uncontrollable – and catastrophic – asymmetric lift during takeoff and landing.

The internally blown flap seems to be potentially the most efficient STOL system, but requires development of a propulsion system specifically tailored to the aircraft. It appears that an externally blown flap STOL aircraft could be developed several years earlier than internally blown flap or lift-fan types. The externally blown flap airplane, however, has more problems with noise generation and engine-out controllability.

Experimental aircraft are needed to permit study in flight of the operational problems of advanced jet-type STOL aircraft. Flight research using such aircraft would also provide data for establishing certification standards. Handling quality criteria for STOL vehicles would be derived from analyses of flight-test results of experimental vehicles as well as data already available or being obtained on certain current propeller STOL aircraft and aircraft that have been modified to simulate STOL characteristics. Flight tests of the experimental aircraft will also provide data to industry to aid its development of prototype and production aircraft.

For many years, V/STOL aircraft have been under extensive study and research. A number of V/STOL flight vehicles of varying degrees of sophistication have been built and flown (Fig. 4.7), but the helicopter is the only operational V/STOL type available today. Although the helicopter has proven very useful in military missions, it has not been even marginally successful in commercial transport. High operating costs, high downtime, low speed, poor ride quality, and noise have been too much to overcome.

Conventional and compound helicopters, tilt-rotor, tilt-wing, and lift-fan aircraft appear to be the most promising types of V/STOL aircraft. Noise generation and controllability/performance with one engine out are critical problems for V/STOL aircraft, as they are for STOL aircraft.

Advanced helicopters can probably be developed in the near future, but their inherently low speed will limit them to short-range applications, particularly intraurban. Efforts are being directed toward reducing costs, improving ride quality through reduction of vibration, and reducing noise levels. Relatively poor handling qualities must be improved, particularly for instrument flight conditions in terminal areas.

Of the other promising types, the compound helicopter is further advanced, with the tilt-wing technology fairly well in hand because of several experimental aircraft that have been built and flown. The development of operational lift-fan V/STOL aircraft will take longer than the development of advanced helicopters, compound helicopters, or tilt-wing aircraft. Lift fans inherently generate more noise than rotor systems, so noise reduction is a prime concern. Because the engines must provide all the lift for the aircraft during takeoff and landing and then must be stowed for cruise flight, the engines must have high thrust-to-weight and thrust-to-volume ratios (above 12/1 and 400/1, respectively, as compared to 6/1 and 200/1, respectively, for current CTOL cruise engines). Much research and development on engines is required. Lift-fan aircraft tend to have a high cruise speed, which makes them attractive for the longer short-haul flights (100 to 500 miles).

The advanced rotor aircraft – using a rotor system that can tilt or fold, or both – will probably require the longest development period. If practical methods of stowing the rotor system can be achieved, however, this aircraft could combine the low noise and hovering efficiency of a rotor aircraft with the high-speed cruise capability of a jet aircraft.

The technology for many of the V/STOL concepts is not validated sufficiently to give manufacturers the confidence they must have to risk entering development of prototypes for possible airline use. Even if the missions were clearly discernible to the manufacturers and to the airlines, there would still be a need for pre-prototype aircraft to evaluate the operational problems, to establish the technical feasibility of

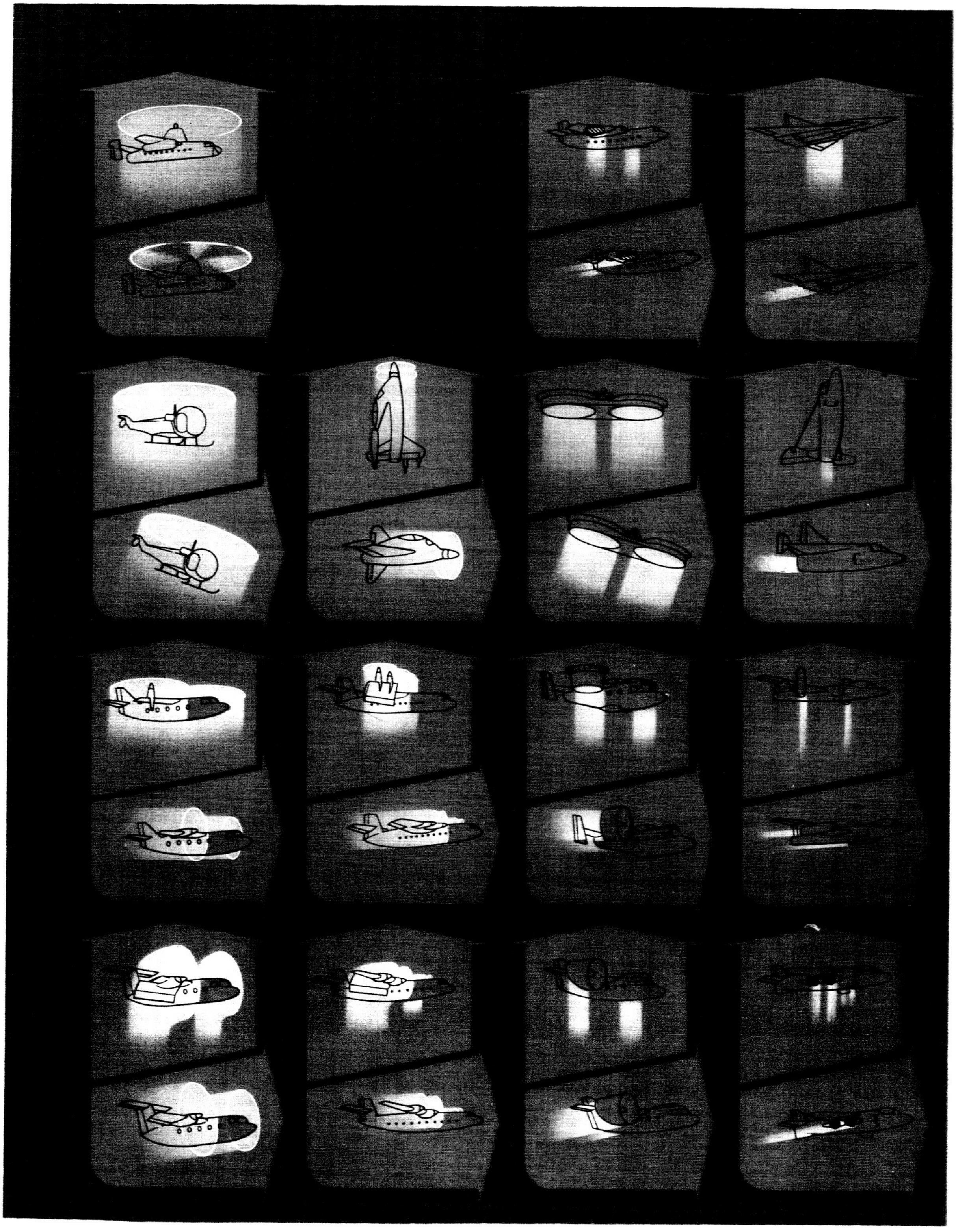


Figure 4.7. The V/STOL aircraft family. *Source: Ref. 4.*

a given concept and to show that it could be viable as a commercial venture. An example might be an experimental vehicle using the tilt-rotor principle, to determine whether the problems revealed in flight tests of the Bell tilt-rotor research vehicle in the late 1950s have been solved by the experimental and theoretical R&D carried on by Government and industry during the last 10 years.

Research and development on VTOL aircraft must cover a variety of vehicles. There is particularly a need for combined technology development and market/vehicle trade-off studies to resolve the areas of uncertainty and identify promising concepts. The operational characteristics and problems of V/STOL aircraft also need continuing study.

Long Haul

Long-haul jet aircraft represent the highest level of vehicle development yet achieved in air transportation. The introduction of the jet transport has essentially eliminated both ships and trains from competition for the long-distance travel market. The design, development, production, and sale of U. S. jet transports, both at home and abroad, have become important elements in our economy (see Fig. 4.8).

If air transportation is to be offered at a reasonable (and internationally competitive) fare, and foreign aircraft sales are to be maintained, improvements must be made in three major areas: efficiency, safety, and noise.

Figure 4.8. Flight line at Seattle.
(Courtesy of The Boeing Company)

If, by the early 1980's, U. S. manufacturers and U. S. airlines are in an improved financial position, they may be expected to be actively considering a new generation of aircraft. The impetus will probably be twofold. First, advancements in technology will make possible the design of aircraft with considerably improved operating characteristics, and, second, the growth of long-haul passenger business may require aircraft with a larger payload capability than the 747 (perhaps 600 to 1000 passengers) for operation on major routes.

The first-generation supersonic transports are expected to carry a major share of the scheduled overwater traffic during the 1980's. Aircraft of the 1970's will probably not be allowed to fly supersonically over land. Hence, the major goal for aircraft of the 1980's will be to develop the best aircraft for overland operations on long-haul routes. Three possibilities exist: a near-sonic ($M \sim 1.0$) aircraft; a boom-free, low-supersonic aircraft ($M = 1.1$ to 1.3); and a low-boom supersonic transport ($M = 2$ to 3).

The greatest benefits in time-saving to the traveling public would be obtained with the "low-boom" supersonic transport. The development of such a transport, however, is predicated on the assumption of a breakthrough to make possible a supersonic transport with acceptable sonic-boom characteristics. This, admittedly, is a high-risk project, but the benefits that would accrue from such a vehicle justify a concentrated R&D program in propulsion, aerodynamics, and structures to reduce sonic boom to an acceptable level.

The near-sonic or "sonic" transport would incorporate the latest technology in materials and structural design to increase the payload fraction; improved propulsion systems to reduce the fuel consumption; and provide a quiet, pollution-free

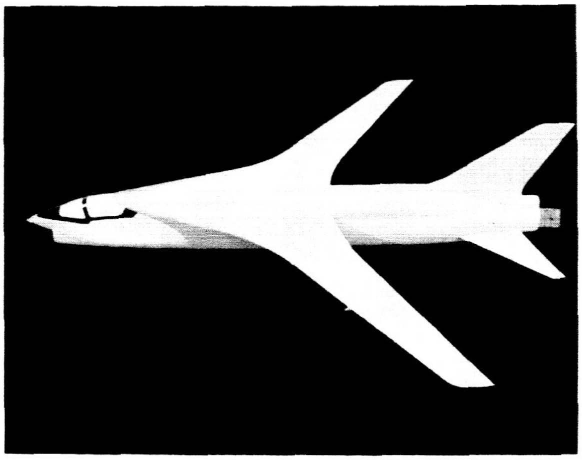


Figure 4.9. Model of modified F–8 with supercritical wing.

power plant, and the supercritical aerodynamic technology recently developed by NASA. The supercritical technology has been developed in wind tunnels using very smooth, carefully contoured models. Confirmation is needed in flight on real aircraft – whose wings are not as smooth and do not conform as exactly to the desired contour – to assure that the benefits can be realized in actual operations, and to reveal problems that require further attention. An F-8 airplane is being modified to incorporate a supercritical wing and contoured fuselage (similar to the model shown in Fig. 4.9), and thus validate in flight the supercritical-wing concept. Additional flight research may be required to validate more representative transport configurations, elastic structures, high-lift devices, and lateral-control provisions.

Research is needed to design shapes that will operate efficiently near the speed of sound. Work is needed to develop automated methods of structural design and fail-safe structures. Research and development is also needed on new lightweight, high-strength, high-stiffness structural materials such as fiber composites of boron and carbon. To provide the experience and confidence required to design a commercial aircraft, the research results will have to be validated by designing, building, and testing large structural specimens. If the "sonic" transport is to be a significant improvement over stretched versions of the wide-body "jumbo" jets, a vigorous R&D program in such areas must be started and maintained over the next 10 years.

The low-supersonic transport cruises at the highest speed possible without producing a sonic boom on the ground. The concept is based on the theory that if the ground speed of the aircraft (i.e., its actual velocity relative to the ground) is lower than the speed of sound at ground level, the sonic boom created by the aircraft flying at $M = 1.1$ to 1.3 will not penetrate to the ground as a boom but will dissipate into an almost inaudible rumble. Recent experimental tests indicate that the expected effect does in fact occur. An interesting result of the speed criterion for this aircraft (ground speed about equal to the local speed of sound) is that it would have equal block times regardless of head winds or tail winds. This would be of particular importance for westbound trips in the United States. It must operate, however, at a speed at which aerodynamic and propulsion systems performance are inherently poor (Fig. 4.10). To attain reasonable performance, a highly tailored and carefully integrated configuration must be developed. R&D is necessary to obtain an optimum aircraft for this speed range.

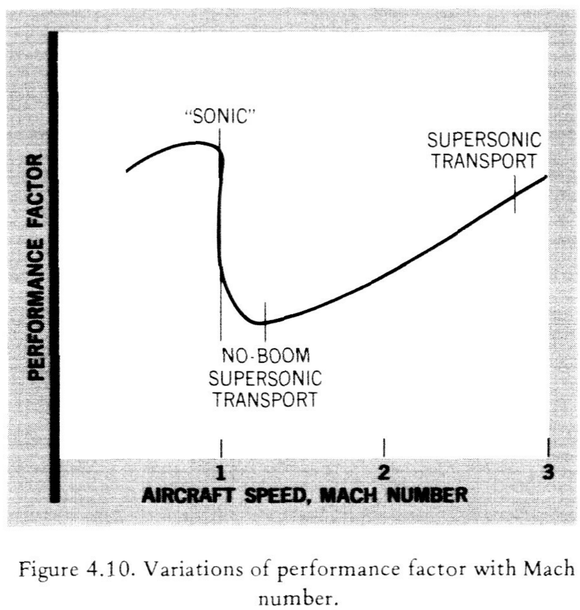


Figure 4.10. Variations of performance factor with Mach number.

By the late 1980's, a new, improved, supersonic transport for intercontinental (overwater) operations will be needed. It should have better range and payload capabilities than current supersonic transports. R&D should focus on propulsion-system technology to produce lighter engines with lower specific fuel consumption, higher transonic thrust, and low noise. Structural research should be directed toward lighter materials and fail-safe structures with temperature capabilities that will allow speeds up to Mach 3. Aerodynamic research should concentrate on improving the lift-drag ratio and on configurations and techniques for reducing sonic boom.

Relatively small decreases in specific fuel consumption can result in significantly large increases in payload. Therefore, propulsion R&D must emphasize reductions in specific fuel consumption. Methane is attractive as a fuel for aircraft because of its higher heating value (15%) and its greater cooling capacity (700% of that for jet fuel). A 25% increase in range is possible relative to a jet-fueled supersonic transport. The cryogenic nature of liquid methane requires new fuel logistic systems, different fuel-handling and storage techniques, and modifications in aircraft design. Its potential advantages are so great, however, that its technical feasibility and economic advantages should be fully explored.

Supersonic transports must be able to operate efficiently over a wide range of subsonic and supersonic flight conditions. The inevitable design compromises are further complicated by the overriding requirement that the propulsion system meet anticipated airport noise restrictions. The inlet noise treatment techniques developed for subsonic aircraft, the choked adjustable supersonic inlet, and the relatively low jet-exhaust velocity expected in approach conditions should alleviate the approach and landing noise problems. Takeoff (sideline) noise, however, will be extremely difficult to reduce to acceptable levels. This problem will require reexamination of all elements of engine design.

Intensive research efforts during the past decade have led to a general understanding of the phenomena and the development of noise minimization techniques, but so far no practical means have been found to reduce the sonic boom to a level that would be acceptable for overland operation. Because of the economic importance of this single factor, vigorous and expanded research is urgently needed to make certain that all possible corrective avenues are explored. Substantial gains will come from increasing the aerodynamic, propulsion, and structural efficiency of the vehicle, but the importance of the problem is such that no new approach – no matter how exotic – should be overlooked, to assure an economically sound, environmentally acceptable second-generation supersonic transport aircraft.

Looking further into the future, current efforts to understand the problems associated with a hypersonic aircraft (M = 6 to 10) should be continued. The effort should be aimed at developing a technology base adequate for the feasibility of hypersonic cruise flight for the 1995 time frame. The information will be applicable to the military and space activities of the country and this effort should be carried on by the Government.

Cargo Service

Little new R&D related to the vehicle will be required for new cargo aircraft. The technologies developed for military aircraft and for civil passenger aircraft will serve. Little new technology is required but the designer must obtain the best aerodynamic performance and weight, consistent with efficient cargo-handling (including considerations of intermodal transfer).

GENERAL RESEARCH AND DEVELOPMENT (NEEDED FOR ALL MISSIONS)

Propulsion Research

Past improvements have resulted from maintaining a broad base of propulsion research. Continuing to improve the propulsion system will

require a strong continuous program, just as a continuing program in the 1950's and early 1960's generated a great deal of propulsion technology that has been and is still being used in development.

Aircraft noise will inhibit the development of all new civil aircraft. The problem will be particularly acute for future short-route-segment STOL vehicles. Community acceptance of these new vehicles will depend on whether the vehicles have significantly lower noise levels (approaching a maximum of 95 EPNdB at 500 feet) than the levels currently required for subsonic transports. Current engine-noise technology has not yet demonstrated that these noise levels can be met in a practical system. It is imperative that research be focused on resolving the problem. NASA has a Quiet Engine Program under way aimed at establishing technology to permit development of an engine that will produce a minimum of noise. Vigorous and continuing effort of this nature is an absolute necessity if future transports are to avoid restrictions on access to new and existing airports. R&D is also needed to determine the best methods of acoustic treatment for inlet and exhaust ducts and to determine configurations of exhaust nozzles that will minimize noise generation.

Air pollution is an important problem in the development of new engines and attention should be given to the problem early in the engine design and development phase. Visible pollution (smoke) can be controlled by improving fuel and airflow distribution, by the use of vaporized burner designs, or by use of fuel additives. R&D in these areas should continue, to assure further reductions. Increasing combustion efficiency at idle-power conditions appears to offer a solution to the problem of some of the nonvisible pollutants (hydrocarbon and carbon monoxide). To accomplish this without sacrificing efficiency at other operating conditions will require R&D in new combustor concepts, such as variable combustor geometry and staged fuel entry. Reduction of pollution from the oxides of nitrogen will be difficult since the formation of this class of pollutant increases with flame temperature and with time available for combustion reactions. R&D is required to determine the effects of temperature and combustion dwell-time. High-density, short-length combustors that reduce the combustion dwell-time appear to offer promise and their development should be continued.

One of the primary objectives of propulsion research is to decrease specific fuel consumption and increase the thrust-to-weight ratio of the propulsion system. Performance may be improved by increasing the aerodynamic efficiency of the inlet, compressor, combustion chamber, turbine, or exhaust nozzle; by improving the efficiency of the combustor; or by increasing the allowable temperature at the inlet of the turbine. Weight can be reduced by substituting new materials with improved properties, by cooling components of the propulsion system so that lighter weight materials can be used, or by improvements in component design that allow equal performance with less material (for instance, shorter inlet designs or compressors that achieve equal pressure ratios with fewer stages).

Aerodynamic Research

The objective of aerodynamic research is to define aircraft shapes that have high aerodynamic efficiency (high lift-to-drag ratio) and satisfactory stability and control characteristics throughout the speed-altitude regime for which the aircraft is designed. All aircraft are required to fly at low speeds during a portion of operations; even supersonic transports, therefore, require research at speeds from subsonic to landing speeds.

The success, made possible by high-speed computers, of complex theoretical methods in accurately predicting aircraft characteristics has provided the aerodynamic designer with a powerful tool. Current computing methods need improving. The accuracy of theoretical methods

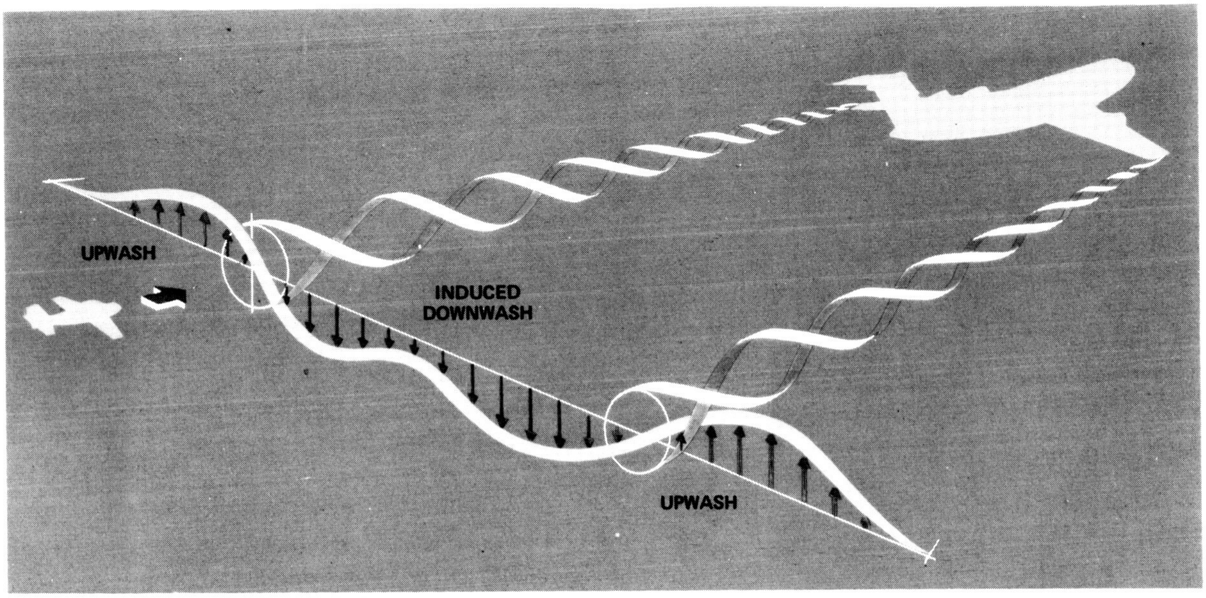


Figure 4.11. The hazard from wing-tip vortices.

needs developing and validating for those flight regimes for which no methodology exists (current methods of estimating performance in the transonic and hypersonic speed regimes are far from adequate for aircraft design). Continued aerodynamic research will result in improved lift-drag ratios for all vehicles – which will reflect directly as lower fuel consumption for a given mission.

Aircraft in flight generate vortices that trail rearward from the wing tips. The energy in the vortices is proportional to the amount of lift being generated by the aircraft. With the recent advent of very large aircraft, the generation of wing-tip vortices in terminal areas has become a serious problem. The vortices from a large aircraft contain such large variations in air flow that another (particularly smaller) aircraft flying into or through a vortex may experience severe rolling motion or even loss of control (see Fig. 4.11 and ref. 5). The hazard is especially severe in terminal areas where many aircraft follow similar flight paths.

The vortex is inherent to wing-generated aerodynamic lift and thus cannot be completely eliminated. It is hoped, however, that research will discover methods to generate a number of weaker vortices rather than one strong vortex, or methods that will cause the single vortex to have a larger diameter and thus lower velocity.

Aircraft Operating Procedures

All avenues of noise reduction must be vigorously pursued if the transport aircraft is to become an acceptable neighbor. Research and development must be continued in the fields of operational procedures (and the necessary instrumentation) to arrive at takeoff and landing procedures, usable under all weather conditions, that will reduce the noise exposure of the airport's neighbors.

Structural and Materials Research

The objective of R&D in structures and materials is to reduce the weight of the aircraft structure and its cost of fabrication. Reductions in weight and cost can be achieved by more efficient structural arrangements or by the use of more efficient materials.

Aircraft of the future, particularly those for supersonic flight, will have more complex shapes

than current aircraft. Structural research should be directed toward producing these complex shapes with minimum weight and cost. New structural configurations, such as honeycomb, have been developed in recent years, and research effort is needed to insure that the best structural configuration can be selected for each new application. New structural materials are becoming available and more will be introduced in the future. Research is needed to arrive at structural configurations that will make maximum use of the capabilities of the new materials. The advent of the high-speed digital computer has made very complex analyses of structures feasible. R&D effort is needed to assure the full exploitation of this capability in future structural design.

Avionics Research

The current and projected increase in air traffic densities combined with the introduction of new aircraft types with widely varying performance characteristics, presages a need for increased performance, new capabilities, and widespread application of avionics equipment to all classes of aircraft. Emphasis must be given to improvements in the air traffic control system to allow it to handle the greatly increased traffic expected in the future. Both ground-based and flight avionics equipment must be greatly improved to provide a high level of safety for the greatly increased numbers of aircraft. At the same time, it is important to reduce the workload of both the pilot and the controller on the ground. The pilot's workload can be reduced by increasing automation on board the aircraft and by automating communications between the aircraft and the ground. The controller's workload can be reduced by upgrading the ATC system as discussed in the "Air Traffic Control" section.

The practical achievement of all-weather landing would provide direct benefits to air transportation by reducing cancelled and diverted flights, as well as by reducing the safety hazards associated with running out of reserve fuel while flying to an alternate airport. Safety is the prime consideration in any system that will allow landing with zero visibility. Two independent systems may be desirable for safety. It will be crucially important to convince pilots of the reliability of any systems proposed. The use of automatic landing systems even in good weather could improve the overall safety level and allow steeper approach paths with consequent noise reductions.

In all cases, and for all classes of aircraft, continued effort is needed to reduce the size, weight, and cost of the avionic equipment. At the same time, the pilot's workload must be reduced and he must have displays of the information he requires for safe and efficient operation of the aircraft.

RESEARCH AND DEVELOPMENT REQUIREMENTS

The Joint Study, with the participation of NASA, DOT, DOD, and industry, evaluated the level of the research and technology effort required to maintain the data base needed for air vehicles to be used by the civil aviation community. The research and technology requirements are those considered essential to the continued growth of civil aviation, to the requirements of improving the safety of flight, reduction of noise levels and pollution due to propulsion emissions, and to the maintenance of U. S. superiority in the field of civil aviation. The results of this evaluation indicate the need for an expenditure of $260 to $340 million per year over the next several years to assure timely solutions to the many problems previously discussed. This effort represents only the R&T directly applicable to civil aircraft.

POLICY ISSUES

One of the basic policy issues of air vehicle development relates to whether the Government should support pre-prototype aircraft, and if so, what the criteria for selection should be, and the roles of the several Government agencies involved.

There are at least three kinds of pre-prototype aircraft. The first is referred to as a research aircraft; its primary purpose is to develop technology, to uncover problems of flight not detected by theory or by wind-tunnel models, and to demonstrate that a given aircraft concept is feasible. The V/STOL research aircraft built during the past decade illustrate the research aircraft approach. The usefulness of this type of flight equipment is also illustrated by the highly successful series of postwar research airplanes, including the X-1 and the X-15. The second kind of pre-prototype aircraft may be termed an experimental aircraft, intended to demonstrate that the appropriate technologies have been brought to a level suitable for their use in an operational aircraft. The third kind is the demonstration aircraft, intended to demonstrate, in a normal operating environment (including airports and air traffic control systems), the capabilities possible in a production aircraft. The objective is to stimulate the development of a new transportation system. An example of this is the 707 prototype aircraft (the Boeing "Dash-80") that was test-operated in a normal operating environment.

An important question in considering the need for a Government role in pre-prototype aircraft is whether private enterprise would assume the development risk without Government assistance. In the case of STOL and V/STOL aircraft, the risk is unclear. A demonstration program will change this risk situation and encourage the development of short-haul air transportation systems attractive to the public.

In the case of an advanced subsonic or transonic transport, the risk is much different. Aircraft manufacturers have in the past developed new long-haul transports about every seven years and have in general applied the best current technology in each of these developments. The latest examples are the family of 747's (started in operation in 1970), and the wide-body aircraft that will shortly begin operation. If their financial circumstances permit, it may be expected that the aircraft manufacturers will develop a new family of long-haul transports in the early 1980's. An experimental aircraft would increase and improve the technology available for the development of an advanced aircraft. The need for an experimental aircraft should be evaluated, on a case-by-case basis considering the technical and financial risks involved and the benefit to the public.

Another issue relates to the continuation of the past and present industry-Government partnership in performing R&D to advance the present state of the art. In 1929, the editor of *Aircraft Engineering*, commenting on the research work being done by the National Advisory Committee for Aeronautics (NASA's predecessor in aeronautical research), said, "The present-day American position in all branches of aeronautical knowledge can, without doubt, be attributed mainly to this far-seeing policy and expenditure on up-to-date laboratory equipment." This statement is probably truer today than when it was made, since the last 20 years have seen an unprecedented advancement in the state of the art. A continuation of this policy is vital if the United States is to continue as a world leader in civil air vehicles.

CONCLUSIONS

The growth of air transportation has been paced by the development of new, improved air vehicles over the years. The present Government-industry partnership in support of R&D must be continued to assure U. S. leadership in commercial air transportation and in the production and sale of air vehicles. Many pressing problems must be attacked and solved in the immediate future if air transportation is to continue to grow and improve. Foremost is the problem of aircraft noise. The present effort must be expanded to assure that future aircraft will be acceptable to the airport neighbors and those who live or work under flight paths. Concentrated research and development is needed to eliminate pollution of the atmosphere. Work needs to be done on STOL- and VTOL-type aircraft to provide the data necessary to establish their future in

the short-haul market. Continued R&D to improve long-haul and short-haul CTOL transports is required to assure that safe, efficient transport will be available to fill future needs.

The major policy issue is that of determining the extent to which Government should support pre-prototype aircraft to provide the industry with data that would reduce the risk in embarking on a new program. The current policy of the Government of supporting R&D to further the technology and extend the state of the art should be continued.

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AIR TRAFFIC CONTROL

INTRODUCTION

The air traffic control (airways) system is composed of facilities, regulations, and personnel providing services and standard procedures for the movement of civil and military aircraft in airspace within the jurisdiction of the United States. It includes the navigation, weather, and air-traffic control (ATC) facilities necessary to meet the objectives of safe and efficient use of the airspace. The ATC facilities include radar systems, which are used for data acquisition and control centers, towers, and communications systems. These ground-based elements must operate effectively with airborne navigation and communication equipment to provide, with full participation and responsibility by the pilot, an effective system of air-traffic management.

The system as it has evolved from the late 1940's has grown significantly because of the rapid increase in traffic and the necessity to assure safety by controlling traffic separation in a real time sense. At present, the system includes 27 air route traffic control centers, 287 ATC towers, 47 combined flight service station towers, and 336 flight service stations. Ninety long-range radar and radar beacon systems provide data on aircraft position to the air route traffic control centers, and 125 short-range radar and radar beacon systems supply data to the terminal facilities. The navigation system includes 946 enroute navigation and nonprecision approach aids and 304 instrument landing systems. Other landing system aids include 627 nondirectional beacons and 292 all-weather approach lighting systems.

The availability of ground radar and the remoting of data from radar sites have enabled the ground controller to maintain safe separations while providing instructions and advice to individual aircraft as he manages the traffic flow. However, the current system is still based on manual control using voice communication, and the data acquisition systems are restricted in capacity and accuracy. Thus, it is not possible at present to provide full service to all aircraft, and there is increasing concern over safety as well as capacity limitations.

Substantial near-term improvement can be effected as adequate funds become available for upgrading the current system using existing concepts and available technology. With the recent passage of the Airport and Airway Development Act of 1970 (ref. 1), it is estimated that the total facilities investment could be increased from the current value of $1.7 billion to about $4.0 to $5.0 billion in 1980. Increased investment, however, must be accompanied by increased productivity of the controller staff if system operating costs are to be contained as the system capacity is expanded. Continuation of present methods of increasing the size of the controller force at a rate proportional to the traffic growth would result in excessive operating costs.

Recently, the DOT Air Traffic Control Advisory Committee completed an 18-month study intended to recommend an air-traffic control system for the 1980's and beyond (ref. 2). Because the current problems are so critical, however, the committee emphasized immediate needs as well. The result was a set of comprehensive recommendations addressed primarily toward solving short-range ATC problems by upgrading the present radar beacon system used for surveillance and by progressively increasing the use of ground computing and automation based on limited modification of present control concepts. The committee also pointed out the need to examine new concepts, new technologies, and new policies for the longer term improvements and recognized the necessity for a research and development program to provide a sound basis for implementing the system required in 1990.

AVIATION GROWTH AND ITS EFFECT ON AIRWAYS SYSTEM DESIGN

Aviation forecasts indicate that the total number of operations will double at approximately 10-year intervals. The number of aircraft

requesting control service, however, is expected to grow at an even faster rate since the demand for services from aircraft operating under Instrument Flight Rules (IFR) is expected to triple by 1980 and increase eightfold by 1995. The total need for service in the terminal area, to aircraft under Visual Flight Rules (VFR) as well as IFR, is expected to increase between 10 and 15 times by 1995 as a result of the combined effects of traffic growth, implementation of terminal control areas, and additional control towers. Overall growth in the high-density terminal areas is forecast to follow generally the national growth pattern, doubling by 1980 and increasing fourfold by 1995. These forecasts are based on growth anticipated as a result of present policies and vehicle types.

The initiation of policies for the development of new transportation services would, in all probability, further increase the demand for services. For example, development and use of STOL and VTOL vehicles to meet a high percentage of the short-haul demand would nearly double the load on the IFR system. The use of these vehicles in high-density areas would probably require segregated route structures in the vicinity of each STOL/VTOLport. For both safety and economy, new automated control concepts would be needed to permit frequent interurban flights.

Traffic increases the interactions between controlled and uncontrolled aircraft with a consequent deterioration in system safety since the ATC system only maintains separation between individual IFR (controlled) aircraft. The separation of IFR traffic from VFR (uncontrolled) flights depends primarily on altitude segregation rules and "see and avoid" techniques during climb and descent. The current rate of about two collisions per year between air carrier aircraft (usually controlled) and uncontrolled aircraft is likely to increase to the order of 10 per year by 1980 unless system changes are instituted (ref. 2). Restriction of the number of VFR flights within certain high-density airspace (Terminal Control Areas) is designed to reduce this problem but also acts to constrain traffic growth. Collisions between uncontrolled aircraft are expected to rise in a similar manner. Hence, as airport-airway capacity is increased, system changes must be instituted concurrently to reduce the potential for collisions.

It is well recognized that the combined airport-airways system has already reached capacity at several major airports, and landing and departure quotas are now in effect at some. In addition, studies recently conducted by the ATC Advisory Committee indicated that the present manual control system is approaching its capacity in many high-density areas including much of the northeastern United States. Although aviation traffic growth is inhibited by elements other than the airways system, such as airports and ground transportation, the predicted increase in aircraft density along with the related collision problem dictates that the present navigation, landing, and ATC facilities be either upgraded or replaced.

NEAR-TERM IMPROVEMENTS

The system improvements described herein, needed to achieve the safety and capacity goals for the 1980 time period, are planned by the FAA, taking into consideration the recommendations of the Air Traffic Control Advisory Committee. The R&D associated with validating advanced ATC concepts, evaluating alternatives, and developing the required system components to provide near-term improvements to the ATC system must be completed by the mid-1970's to permit implementation of the system prior to 1980. For this reason, many of the recommendations were based on extensions of existing development programs and, hence represented improvements that could be developed rapidly. Although these improvements, when implemented, will provide system elements that will be useful through the 1980's, further changes are required to accommodate aviation growth beyond that time and to provide for the possibility that growth rates might be greater than expected. The alternatives for this future time period are treated in the next subsection.

The near-term improvements planned by FAA are summarized as follows:

- Increase traffic capacity in large urban areas by expanding the capacity of existing airports. This will require the operation of closely spaced, dual-lane runways. It will also require the upgrading of the electronic and surveillance systems so that all-weather landing and departure operations can be conducted on these parallel runways. This upgrading includes the development of an improved instrument landing system based on microwave scanning-beam technology. Improved methods of detecting wake turbulence must be developed to minimize its effect on airport and terminal area operations. Methods of reducing turbulence must also be pursued.
- Extend the ATC separation service to include all aircraft (IFR and VFR) flying in medium- and high-density regions of controlled airspace, thus maintaining safety in high-density traffic areas. Providing collision-avoidance service from the ground-based automation system will assure such safety by providing collision-avoidance messages to both controlled and uncontrolled aircraft.
- Develop higher levels of automation than will be provided by the initial operating capability of the National Airspace System (NAS) automation program for the enroute control centers and the Advanced Radar Terminal System (ARTS) automation program for Terminal Control facilities. Higher levels of automation will increase the number of aircraft that can be handled by a control sector by assisting the controller in performing many of the decision-making and tactical-control actions. The automation of conflict-control, flow management, and safety-monitoring functions, in addition to the basic automation of the present system, is needed to achieve the required threefold increase in traffic handling capacity for the critical control sectors in high-density areas. The implementation of an automatic ground-air-ground data link is also required to transmit computer-generated control instructions directly to the pilot/autopilot.
- Upgrade the present ATC radar beacon system to increase accuracy in determining aircraft position, and provide a ground-air-ground digital communications mode. This wide-band digital data link could ultimately replace the present very high frequency (VHF) voice communication system for transmitting ATC separation and collision avoidance messages.
- Improve the very high frequency omnidirectional range-distance measuring equipment (VOR–DME) navigation system to provide the signals required for an area navigation capability in the domestic airspace. The scanning-beam microwave landing system will provide the basis for flexible, low-noise terminal approach routes, in addition to improved accuracy in approach guidance. This type of landing system is much less sensitive to signal reflection problems and will permit instrument landing capability at many sites where present equipment cannot be used. This landing system can also be used, with suitable airborne equipment, to permit automatic landings under all-weather conditions with a resulting improvement in safety by reducing landing accidents.

The benefits to be achieved through these improvements were quantified through simulation and analysis (ref. 2). The results show that the following potential increases in system capacity are possible:

- In the enroute and transition control areas, automation is expected to increase control-sector capacity as follows:
  - National Airspace System (NAS) and Advanced Radar Terminal System (ARTS) Automation 20%
  - Automating conflict detection and resolution 180%
  - Automating flow management and terminal spacing function . . 100%
  - Total increase in control-sector capacity 300%
- In the terminal area and at individual airports where the most critical problems currently exist, implementing these improvements and upgrading the airport-airside system are expected to bring about capacity increases of the following nature:
  - Implementing the dual-lane runway systems (described in the "Airports" section), but still using present manual-control procedures . . 42%
  - Automating the sequencing and spacing function and implementing the automatic ground-air-ground digital data links with some procedural changes 48%
  - Reducing minimum longitudinal separation standards by increasing the level of automation and by making other system improvements 68%

    The total potential gain per runway 158%

Implementing these planned improvements will bring other benefits. These include reduction in delays of up to 35% which can be of significant economic importance (e.g., it is estimated that delays in 1969 cost $158 million). A significant reduction in pollution would also result (22 million pounds of pollutants were emitted during traffic delays in 1969). Another benefit results from the capability of the new landing system to permit steeper approach paths since this will allow traffic routing that minimizes noise exposure to the community adjoining an airport.

FUTURE SYSTEM CONSIDERATIONS

Since the implementation of the short-term improvements defined in the previous section will require several years to develop and implement in the field facilities, the earliest gains in capacity will be achieved largely by increasing the number of control sectors. Studies have indicated that the traffic capacity can be about doubled in high-density areas by this method before the control sector is reduced to the minimum size compatible with effective control. Implementation of the short-term improvements defined above would bring a threefold increase in capacity by increasing controller productivity. The combined effect would be to increase the capacity of the high-density areas by a factor of six.

Because of the time required to implement improvements, a shortage of system capacity will continue to exist for the immediate future. If traffic distribution can be improved by influencing the location of new airports, by expanding existing airports, and by revising airways route structures, it should be possible to handle the expected traffic growth well into the 1980's. Further system changes will be needed at that time. The Air Traffic Control Advisory Committee gave some consideration to such long-term improvements, but because of many factors, their work was limited. They recommended, however, that extensive research be conducted toward very advanced levels of automation and the use of satellite systems.

It is important to recognize that, because of various constraints within the Government, adequate effort has not been applied to the analysis of advanced system concepts, nor to related research, performance studies, and evaluation of technology that might be applied in the future. The complexity of the problem and the fact that expenditures of about $40 billion are expected

during the next two decades for ATC equipment and its direct operating costs, plus additional major Government expenditures for airborne ATC equipment by the military, make such effort essential. Even if additional capacity were not needed in the 1980-1990 time period, the opportunity to achieve reduced operating costs, greater safety, and improved performance would be sufficient to justify the required research activity.

It must be recognized that projected demand will outpace system capacity for years to come unless there is concerted Government action. A careful assessment of the relative merits of new concepts of ATC and the related technology alternatives is required on a continuing basis to assure the upgrading of the airways system as rapidly as resources and technology will permit. This continuing assessment will minimize the possibility of making too large an investment in capital improvements that might become prematurely obsolete and will, at the same time, guard against overoptimism about time-availability of new technology.

The required long-term improvements are expected to come from research and development activities in three major areas: the development, simulation, and evaluation of new traffic control concepts; the definition, simulation, and analysis of various system approaches; and the development and application of new technology in the subsystem areas to provide new and improved equipment capabilities. These activities are treated separately in the following discussions. A subsequent subsection will also outline policy changes needed to achieve the improvements in system capacity and controller productivity.

The analysis of advanced concepts for traffic control and flow management must be carried out with accurate knowledge of the performance that could be achieved with advanced airborne equipment and new ground- or satellite-based ATC elements. Concepts and equipment that might differ radically from that currently in use should be considered if a clear advantage is shown during analysis of the technical, operational, and economic factors involved.

Traffic Control Concepts

The present ATC system is based on computer-aided manual techniques using ground voice control of IFR flights while VFR flights operate essentiallly independently. Separation between IFR and VFR flights is achieved by restrictions on VFR traffic in large segments of terminal area and high-altitude airspace and by altitude separation rules when aircraft are in level flight at the lower altitudes. During good weather conditions in terminal areas with no airspace restrictions, separation between IFR and VFR flights is normally on a "see and be seen" basis with advisory information from the ground controller as workload permits. Near-term improvements have been proposed that would provide radar surveillance of all flights in the higher density traffic areas with instructions to resolve potential conflicts issued to both IFR and VFR flights. An increased level of automation based on computer-generated control instructions and an automatic ground-air-ground data link would relieve much of the routine workload on the ground controller and would automatically detect and resolve potential collision situations.

As traffic density continues to increase and control problems become more complex – as is the case for control sectors that are sequencing and spacing aircraft in high-density terminal areas – the control workload, measured in terms of control instructions generated and delivered, increases greatly. The result is a reduction in the number of aircraft that can be handled per control sector. Capacity can be increased to a point by increasing the number of sectors and reducing sector size. However, the limit of this gain is reached when the sector size becomes too small to provide effective control. In addition, the increase in intersector coordination workload will further serve to reduce traffic. Clearly, any system that depends on a controller to "hand-carry" each controlled aircraft in high-density areas is capacity-limited, and the capacity limit is set by controller workload saturation and minimum effective sector size. The cost of this approach is also a major factor. Each

new sector requires communications frequencies and facilities, sector displays, and data processing capacity to operate these displays in addition to new controllers to operate the sector. In such a system approach, the cost of operation increases directly with the number of operations until the system saturates.

A measure of relief is afforded by utilizing a computer to perform the "tactical" functions (generation of clearance changes including headings, speed, and altitude instructions), and more routine functions. Currently, in high-density sectors operating at capacity, communication channel utilization reaches approximately 70%. Automation of the control functions would allow some slight increase in channel utilization time and traffic controlled per sector. However, the gain is small unless the ground-air-ground voice communications bottleneck is removed. Implementation of a digital data link serves to provide the vehicle for the next increase in traffic-handling capability. The data link, however, cannot be effective if the human controller must still approve each control action. Hence, one consequence of transition to an automated tactical system is the change in controller role from one of real-time tactical control to one of longer term flow planning ("strategic control") and monitoring of computer performance of the tactical function.

The system improvements to be implemented by 1980 will provide automation in the ground ATC system of the routine, tactical, and flow-planning functions. The gains in capacity to accommodate the traffic expected after the 1980's, however, will require a change in the basic method of control in order to reduce the control workload per aircraft. A change with high potential would be a strategic control concept characterized by the assignment of a route-time profile to each aircraft. This approach would use the ground computer system to perform a very much upgraded planning and flight monitoring function while returning to airborne systems the responsibility for the tactical control (i.e., speed, altitude, and heading changes) needed to achieve the assigned profile.

Several alternatives exist for obtaining the benefits available from use of strategic control methods. One approach would provide a ground ATC system that automated both the strategic and tactical methods of control. In this approach the computer would generate the route-time profiles and issue tactical control instructions to the aircraft to achieve the desired performance. Although this system would reduce the ground-air-ground communications workload somewhat, the reduction in workload per aircraft would not be large. Further, major ground system failures would affect the level of airborne safety to a greater extent than a different approach, a system where the entire strategic plan would be available in the aircraft and tactical control would be conducted therein. The latter approach, which appears to provide more effective system operation and reduced workload for itinerant flights operating on IFR clearances, would relegate the tactical functions back to the aircraft for those aircraft equipped to accept and follow route-time profiles. This approach should reduce ground ATC processing, control, and communications workload per flight to the point where further major expansions in capacity would be possible.

It must be recognized that not all user missions are ideally suited to flow (strategic) control. Hence, it is expected that users will continue to be segregated, to the extent possible, by airspace volume based on the type of service desired. Airborne equipment requirements would be determined by the service desired and the airspace volumes used. Hence, for the foreseeable future, the ATC system must accommodate a spectrum of airborne capabilities. Further, the realities of daily operations require that the system efficiently cope with disturbances such as moving weather fronts and thunderstorms. Segregation of users by equipment capability into different airspace volumes, however, allows implementation of strategic control in some airspace. Since a higher ATC system workload is associated with handling nonequipped aircraft, the capacity of

the airspace volumes used by these aircraft may well be less than that of the airspace volumes used by equipped aircraft.

The short-term improvement program (items 1 and 2 in Table 4.1) in concert with a doubling of the number of control sectors in high-density areas will result in a sixfold increase in capacity by providing automation of routine, tactical, and planning functions. This program will provide an improved level of service to the users and will meet the growth requirements at least through the 1980's. Meeting growth requirements beyond 1990 will necessitate implementation of new control concepts, such as some form of strategic control combined with increased structuring of the airspace. Recent analyses of the gains that could be achieved through use of the strategic concept were based on models of a route from New Orleans to Boston via Atlanta, Washington, and New York. In addition, the Chicago terminal area was modeled for various control concepts. The results indicated that a 30% gain in capacity (beyond the 1980 system) could be achieved if all itinerant air carrier and military IFR flights were conducted on a strategic control basis. The models were also exercised to determine the gain that could be achieved if *all* itinerant IFR flights were conducted on a strategic control basis. This approach resulted in a predicted gain of 4.4:1. Although the latter case only determined the maximum gain from this concept, the results point out the system gains to be achieved by encouraging or requiring higher levels of IFR capability in general aviation aircraft. The capacity gains that may be achieved from implementing selected alternatives are summarized in Table 4.1. The tabulation also indicates the approximate time period in which the capacity gain would be required.

Table 4.1 relates to capacity increases in high-density areas. At present, 64 high- and medium-density terminals handle in excess of 80% of the commercial passenger operations and 70% of the total instrument operations. In addition, approximately 60% of the general aviation fleet is based in these areas. Hence, any system concept that does not solve the high-density terminal and associated enroute control problems will do little to increase the capacity of the IFR system. Figure 4.12 shows the approximate level of system capacity that can be achieved by the Advanced Radar Terminal (ARTS) and National Airspace (NAS) systems, those systems with the short-term recommended improvements added, a hybrid tactical-strategic system where air-carrier and military itinerant flights are conducted under strategic control, and an all-strategic control system. The curves represent the approximate increase in system capacity that can be

TABLE 4.1. CAPACITY INCREASE AS A FUNCTION OF CONTROL CONCEPT

ATC SYSTEM CONCEPT	CAPACITY INCREASE FACTOR[a]	APPROXIMATE TIME PERIOD REQUIRED[b]
ADDITIONAL CONTROL SECTORS (COMPUTER-AIDED MANUAL)	2.2	1970-1980
AUTOMATED TACTICAL (SHORT-TERM IMPROVEMENTS)	6.0	1980-1990
AUTOMATED HYBRID TACTICAL-STRATEGIC (COMMERCIAL-MILITARY AIRCRAFT COMPUTER EQUIPPED)	7.8	1985-1995
AUTOMATED GROUND STRATEGIC AND AIR TACTICAL (ALL IFR AIRCRAFT COMPUTER EQUIPPED)	26.4	1995-2005+

[a]*All numbers are referenced to 1970 levels and are cumulative.*
[b]*Periods are valid if present forecast of traffic growth is valid.*

achieved in high-density areas. Each curve follows the demand line to the point where airspace saturation starts in the major terminals. The curve then rises at a slower rate than the demand line to show continued growth in areas where saturation has not yet occurred. The difference between the two lines (i.e., demand line and system concept capacity line) represents a lack of system capacity.

Figure 4.13 represents the approximate size of the controller work force required for each of the system concepts. The size of the work force, in each case, is that required to achieve the capacity gains shown for the same concept in Figure 4.12. For the ARTS and NAS system a growth in traffic capacity (based on 1970) of four to five times can probably be achieved by expanding the controller force to between 80,000 and 100.000. By comparison, a growth of eight to ten times appears achieveable by implementation of the short-term improvements supplemented by the hybrid control concept. In this case, it appears possible to level off the controller force

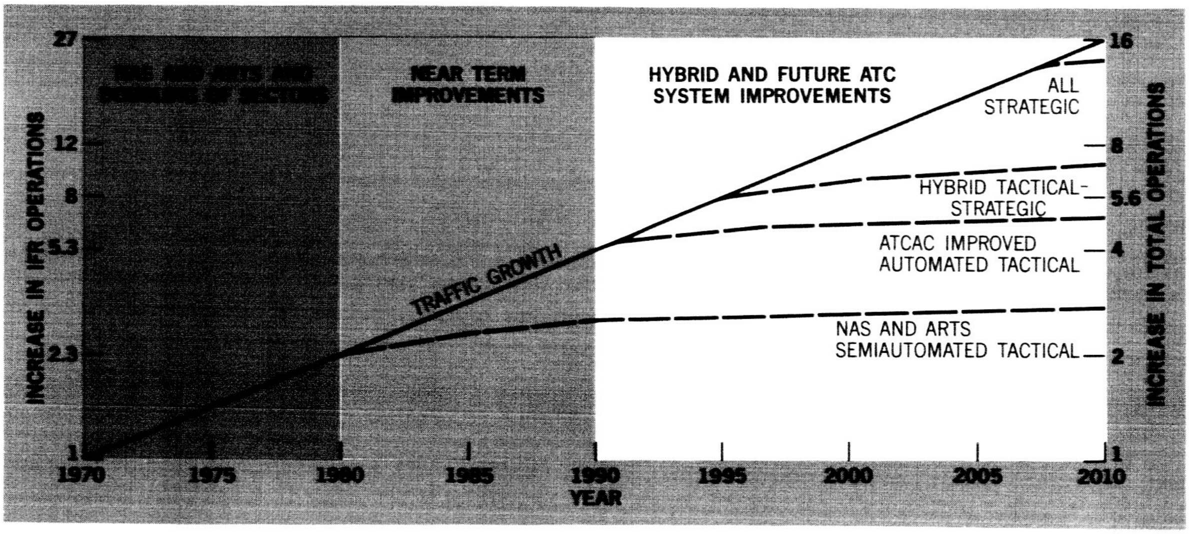

Figure 4.12. Capacity gains versus control concept.

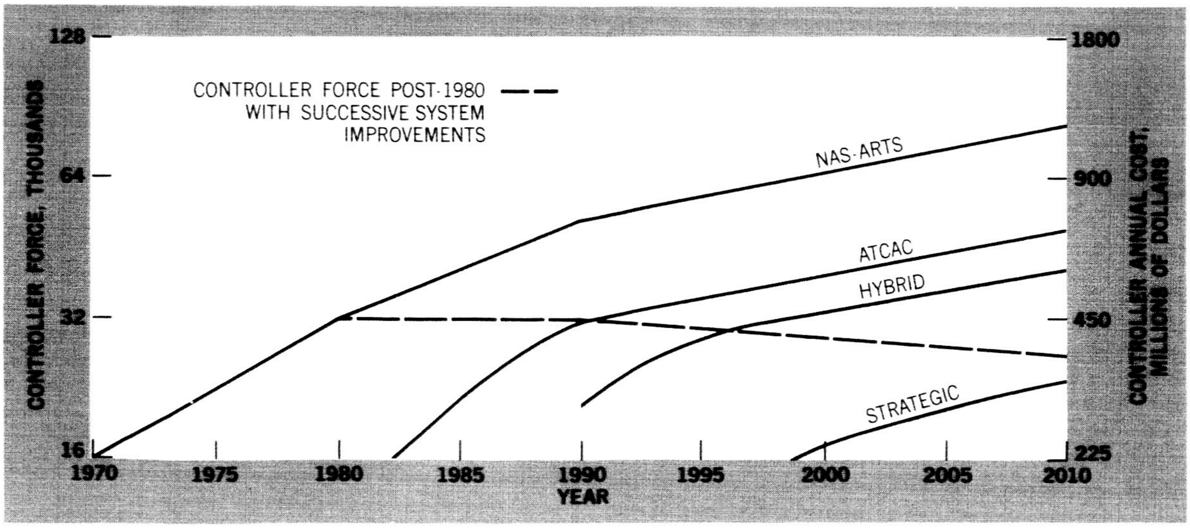

Figure 4.13. Controller force versus control concept.

at about 30,000 if these system changes are instituted at the times shown.

The curves were based on present forecasts of traffic growth. If traffic grows substantially faster, the time cycle of introducing the new concepts and their supporting ground and airborne systems must be expedited. Similarly, a reduction in the rate of growth would delay the time at which the improvements would be needed. Although the curves show each concept being introduced at the moment when the previous concept has caused traffic saturation in some high-density areas, earlier or later introduction is also possible. Earlier implementation would appear to offer the possibility of earlier leveling off of the growth of the controller work force. This potential reduction in cost, however, must be balanced against R&D development times for new concepts and system equipment. A major consideration with respect to the latter is the cost and time required for users to equip their aircraft with the required new avionics. Later implementation, in all cases, results in a lack of airway system capacity in the high-density areas.

Since the majority of the capacity gains and workload analyses are based on limited analysis, the curves are intended to show only general trends and the need to actively pursue development of improved control concepts. The alternatives used in this example exploited the potential capacity gains to be achieved by evolving to a system using the strategic control concept. Although implementing this concept appears to offer the needed growth, other concepts should be considered and further evaluated.

The R&D activity in this area would include tasks to evaluate, through simulation and analysis, system approaches with various distributions of functions between ground and airborne systems. It would also assess the impact of various policy alternatives, and various traffic-flow management concepts on system performance and cost. The choice of approaches will be affected by the extent to which the ground-air-ground communications load can be reduced by delegating functions back to the airborne electronics system. Systems where the majority of the computations are performed by the ground-based ATC computers and resulting control instructions transmitted to the aircraft impose heavy communications loads on the data acquisition and data link systems. Such an approach tends to favor the choice of a ground-based data acquisition and data link system. On the other hand, systems that depend heavily on an airborne electronics capacity to follow a preassigned route profile tend to be more compatible with satellite-based systems.

Technology

The selection of concepts for application in the long-term improvement of the air-traffic system depends on the development of advanced navigation, surveillance, and automated control techniques, and the use of improved systems analysis and operations research methods in evaluating these techniques for future use. It is possible at this time to discuss only broadly some of the key system elements; however, insight into some of the important research and development needs is given in the following discussion.

Position Determination. Knowledge of aircraft location, including both geographic coordinates and altitude, is necessary for navigation by the pilot as well as for ground surveillance during the management of traffic flow and the resolution of potential conflicts between aircraft. Currently, navigation is carried out using a group of ground-based radio navigation aids that are entirely independent of the surveillance system, which relies primarily on radar (and radar beacon) techniques. These independent navigation and surveillance systems permit a clear separation of responsibility for navigation by the pilot and contribute to overall reliability.

In considering the design of future systems, attention must be given to defining and providing adequate accuracies for both the navigation and guidance systems if the independent systems approach is maintained. Alternatively, a common

primary system can be considered for providing the navigation and surveillance functions; however, in the design of such a system it must be realized that high reliability requirements must be met. A common system might ultimately permit better precision in achieving the desired separation and spacing of aircraft since it would not be necessary to allow for the cumulative errors of two independent systems. Also, it should be noted that certain classes of aircraft cause special problems. For example, VTOL and STOL vehicles operating at low altitudes encounter problems regarding accurate low-altitude coverage by both the current and upgraded radar beacon systems as well as similar problems for the present types of ground-based radio navigation aids. These problems result primarily from the shadowing caused by high terrain or other obstructions between the aircraft and the radar site or navigation aid.

Research and development are needed for fully evaluating position determination methods that might be applied in the future. These methods are discussed in the following paragraphs.

- *Satellite Systems.* Satellite systems can provide accurate surveillance coverage over wide areas with almost no restrictions due to terrain features. These systems can be designed to permit independent measurement of aircraft altitude. However, present technology imposes a weight and cost penalty on the aircraft because communications are required over the 22,000-mile path to a synchronous satellite. Practical limitations on satellite transmitter power also restrict the number of aircraft that can be served with systems requiring high rates of data transfer with individual aircraft. In addition, the geometry involved in determining position from satellite altitude requires greater measurement precision than in many ground-based systems. Nevertheless, satellite systems appear to deserve careful examination for the following applications:

- *Systems for Transoceanic Traffic.* In this case the number of aircraft involved is relatively small, and is restricted almost entirely to large transport vehicles that can carry the airborne systems necessary for communication, surveillance, or navigation by satellite. Alternatively, communication and surveillance functions might be performed by satellites that use inertial systems or other navigation methods. Studies by the President's Science Advisory Committee have shown that annual savings on the order of $50 to $100 million could result during 1978 to 1982 if satellite systems were used to permit more optimum operations over the North Atlantic. For the immediate future, aircraft in opposing lanes are separated laterally by 60 to 120 miles, depending upon altitude assignment, and are spaced 15 minutes apart in each lane. This limits the ability to take optimum advantage of high-altitude winds and to select the best routes associated with origin and destination points.

- *Either Navigation or Surveillance for the Continental United States.* Navigation data might be provided to unlimited numbers of aircraft by utilizing passive techniques not requiring transmission from the aircraft or involving high data rates. Feasibility would be determined by the cost of receiving and computing equipment required on board the aircraft. Another alternative is to provide surveillance of large numbers of aircraft from a single satellite system. It would probably be necessary to use pulse compression techniques to limit the peak power required in the aircraft transmitter and to restrict the data rates and employ advanced coding and detection methods to

permit handling large numbers of aircraft (5,000 to 50,000) in a single system. The feasibility would be strongly influenced by the cost of equipment required in general aviation aircraft. Considerable caution would appear to be necessary in considering systems that involve an integrated data link function since the power required for aircraft-to-satellite communications is about 100 times greater than for aircraft-to-ground communications.

- *Advanced Radar Methods.* These include new radar beacon techniques designed for extensive tracking and communications functions in high-density traffic environments. Full attention should be given to concepts that permit modular system components to meet the economic and weight needs of general aviation aircraft as well as the requirements imposed by compatibility with military systems.
- *Multifunction One-Way Velocity and Distance Measurement Systems Based on Precision Time Methods.* Precise, synchronized time references can be obtained in each aircraft by methods that permit one-way range and velocity measurement relative to ground locations and other aircraft (these are sometimes referred to as time-frequency techniques). System designs are possible that would allow various degrees of ground surveillance along with air-to-air information exchange for traffic spacing and collision avoidance. Attention should be given to methods compatible with the economic constraints associated with various classes of aircraft and the interference and saturation problems resulting from large aircraft population.
- *Multilateration Systems Requiring Transmission to Two or More Ground Locations.* Advanced modulation methods and coding schemes based on modern information and statistical communications theory should be explored as one means of removing current limitations that result in saturation and difficulties in system designs for practical use in the existing frequency spectrum.
- *Hyperbolic Grid Methods Similar to Those Used by Loran–C, Loran–D, Decca, and Omega.* For navigation purposes, position might be determined in the aircraft by a passive, nonsaturable method with data transfer to the ground utilizing high-capacity communications techniques. If ground wave propagation is feasible, coverage would be possible at all altitudes as well as on the airport surface. Also, there is the possibility of simply, yet accurately, measuring ground speed in the aircraft, which could be valuable in controlling flights and maintaining a desired traffic flow.

  Advanced modulation and detection methods are needed to reduce the effects of interference, precipitation static, and atmospheric noise now limiting the usefulness of these systems. Advanced designs employing new microelectronic data processing methods would be required in an effort to seek economically feasible systems with the capability of handling the extra baseline computations that probably are necessary from reliability considerations.

At present, satellites and hyperbolic grid ground-based systems appear to be the only techniques with the potential of providing coverage of aircraft at almost any altitude over a large geographic area. However, considerable development would be necessary to achieve economically feasible airborne equipment.

Communications. One of the most important future needs is the development of radio communications techniques for application in a

high-density aircraft environment. Such techniques are essential to the proper design of communications links needed for ground-air-ground information transfer, air-to-air data exchange, and tracking for surveillance purposes. The present approach employs simple modulation techniques and relatively high powers to assure reliable communications when an aircraft is at low altitudes or when the antenna coverage is not good. Consequently, strong signals are radiated for many hundreds of miles. As the number of aircraft increases, the situation becomes self-defeating because of the interference produced at distances far beyond the desired range of communications.

Research efforts are needed to develop and apply modern statistical communications methods for the high-density aircraft environment. Generally, the approach involves relatively low powers and random-type modulation methods with coding techniques to permit the sorting of signals or, possibly, with a return link to assure that the message is received (and if not, repeated with certain changes until it is received). This is the same technology being applied to high-security, multiple-access military systems and to deep space communications. In the high-density aircraft environment, the emphasis would be on the simpler implementation methods, efficient use of the limited radio spectrum, and obtaining a high degree of reliability without resorting to high powers and creating difficult interference problems. Attention should be given to techniques applicable to both ground and satellite systems.

Related Elements. In addition to systems analysis of basic control concepts and research on advanced position determination methods and communications techniques, several other areas require emphasis in considering future systems. Among these are the following:

- *Computer System Design* Both ground-based and airborne computers are expected to play an important role in future systems. The organization and design of these computers require an intense effort to achieve the reliability to assure flight safety consistent with one accident in one million flight hours, or better. With advanced levels of automation, systems must be free from the effects of failures when considered with backup elements or alternate operating modes. A key item is the design of a ground-based system with computer elements that can be distributed among several geographic locations and operated in a highly reliable, redundant manner so that catastrophic failures at one or more locations would not have significant impact on system performance.
- *Advanced Flight Control Systems.* An important element in future systems will be the capability of air carriers and high-performance aircraft to sustain rigorous operating schedules from takeoff to landing. During much of this time, the flight may be under computer control with key input information from the ATC system and related navigation aids. Increased attention in the future must be given to the capability of advanced aircraft control systems and interaction with the ATC system.
- *Displays.* Effective displays for presenting position along the desired flight path, traffic situations, and navigational data are needed for the higher performance aircraft. In addition, the availability of economic but lower performance versions could greatly influence the method of operating with general aviation aircraft. Advanced display and data presentation methods are also needed for ground personnel.

RESEARCH AND DEVELOPMENT REQUIREMENTS

As may be seen from the preceding discussions regarding near-term improvements and future system considerations, it is important that an intensive research and development program

be initiated now and continued for some time to come to develop solutions for the critical airways problems. These solutions must provide the ability to achieve the safety and capacity goals in an economically viable manner but must not unduly constrain the growth of any of the various aviation segments. In conducting this research, it will be necessary to determine the impact of advanced air-traffic control systems and operational restraints on the design of aircraft and aircraft systems, as well as the impact of new aircraft on the airway system structure. The urgency of vigorously attacking both of these problems can be emphasized by the following: first, the air-traffic control situation is critical now in some major hub areas so improvements are required in the immediate future; and second, a definition of the configuration of the future air-traffic control system, especially with respect to the ground system elements, is needed at as early a time as possible to assure that the implementation of near-term improvements will permit a reasonable transition to the future system.

Near-Term Development Requirements

The following program is based largely on improving existing system elements to achieve increases in capacity as rapidly as possible. This program should permit implementation at the earliest possible date to achieve an increase of at least a factor of three in sector capacity. The major elements of this program are:

- System engineering, simulation, and trade-off studies.
- Development of techniques to permit substantial increases in automation of ATC functions, including flow management, safety enhancement, flight plan processing, integration of automated communications, and data processor expansion.
- Development of an upgraded data acquisition system including data link interrogators, ATC data link transponders, and an improved radar system.
- Development of an upgraded communications system, including expansion of the digital communications network and definition of data link services and message formats.
- Development of upgraded navigation and landing systems, including the improvement of the enroute VHF Omni-Range (VOR) system, development of terminal Precision VOR (PVOR) equipment, capacity expansion of the Distance Measuring Equipment (DME), development of an oceanic navigation system, and development of an all-weather scanning-beam microwave landing system.

Future System Research and Development

The following program should be initiated now to provide a system design for the traffic demands of the late 1980's and beyond. This program must include research, advanced technology evaluations, and development steps as well as concept simulation before the design of an advanced ATC system can be established. The major activities associated with this program include:

- System engineering, simulation, and trade-off studies (including development of new control concepts and approaches for optimum airspace utilization) and economic evaluation of policy alternatives on system design and implementation methods.
- Research on ground- and satellite-based position determination methods for navigation and surveillance and for both functions simultaneously. Attention should be given to highly accurate systems with good low-altitude coverage and the performance of these systems with new landing aids.
- Research on communications techniques for application in a high-density aircraft environment. This includes propagation and multipath effects, and advanced

modulation and coding methods for both ground- and satellite-based systems.

- The development of high-capacity fail-safe ground-based computing systems; highly reliable airborne computers and processing techniques; and advanced data acquisition and display methods.
- Continued analysis of the impact of new classes of aircraft, noise reduction advances, and improved weather and turbulence detection methods.

R&D Funding Requirements

The FAA 10-year plan estimates that the initial automation steps now under way will result in about a 20% increase in controller productivity (ref. 3). A much greater increase in capacity, however, is needed by 1980. The R&D funding level should, therefore, be increased sufficiently to permit implementing near-term improvements by 1980 to achieve a factor of three increase in control sector capacity, as well as to permit a vigorous attack on the future system problems.

The annual R&D funding level required to support the airways program has been estimated for the next 10 years. The requirements for the 1970's average $160 million per year, or a 10-year cost of about $1.6 billion (based on 1970 dollars) (ref. 4).

The projected R&D program for the following 10-year period (the 1980's) is expected to average $200 million per year, or a 10-year cost of $2.0 billion (based on 1970 dollars).

The total R&D program for the next 20 years is designed to meet the capacity growth forecast on the basis of existing or anticipated vehicle types. It also includes development efforts tailored to the unique requirements of STOL vehicles. These include a scanning-beam type of microwave landing system and improved low-level navigation system. It should be noted that the R&D level is based on doubling capacity at about 10-year intervals. If substantially higher growth rates are experienced as a result of rapid implementation of STOL systems or accelerated growth in general aviation, higher funding levels will be required. In addition, it should be noted that R&D funding must provide for the expansion of existing research capability and the establishment of new test facilities to permit development and evaluation of new concepts and equipment in both experimental and operational environments. Some facilities located with operational ATC facilities are needed to evaluate proposed system improvements under normal air-traffic conditions. In addition, a demonstration airport would greatly expedite the development of improved airport systems by allowing demonstration of improvements in all the ground and airborne elements.

POLICY CONSIDERATIONS

Changes in control concept and implementation of new, more capable technologies can produce the desired results only if they are supported by effective policies. The goal of these policies is to produce a system that meets the demand and safety requirements in a timely manner at a minimum overall system cost. The policy considerations presented in the following paragraphs affect both short- and long-term system improvements. The policies are aimed at increasing the speed of implementation to allow the system to "catch up" quickly as well to increase system effectiveness by implementation of a more capable set of airborne equipment in all aircraft flying in the system.

Segregation of Airspace Users

Future systems will continue to provide a spectrum of service levels to permit uncontrolled VFR flight in some areas, controlled VFR flights in other areas, controlled VFR flight in some terminal areas, and IFR operations between many of the nation's airports and throughout much of the airspace. Consequently, the following policy is recommended:

Segregation between airspace users should be based on the type of service (i.e., IFR, IPC, controlled VFR, and uncontrolled VFR). Airborne equipment requirements, pilot proficiency, and rules and procedures for each type of service will be established by Federal Air Regulations.

Performance Standards for Airborne Equipment

Among the major problems in converting to any new system are the time and cost required to convert the airborne avionic systems to the new equipment capability. An associated problem of equal importance is the difficulty of achieving airborne system performance matched directly to the ground ATC system. Variations in airborne system capabilities and performance, in turn, mean that the ground automation system must provide an interface with a wide spectrum of avionic systems of varying performance and capabilities. The impact of processing inaccurate or incomplete data is greatly increased cost in the ground ATC system. The establishment of minimum acceptable performance standards for all airborne equipment interfacing with and forming a part of the ATC system would reduce system costs appreciably.

To reduce the problems and overall system cost resulting from a wide spectrum of avionics equipment capability, the Government must participate in the development of standardized performance specifications for airborne equipment. A second policy is therefore recommended:

> The Federal Government should sponsor the R&D necessary to define performance standards for that portion of the airborne equipment that forms a part of the air traffic control, navigation, communications, and data-acquisition systems, and that is associated with each type of service (IFR, IPC, controlled VFR, and uncontrolled VFR).

Avionics

As aircraft used for IFR flights become better equipped and capable of operating more efficiently under new control concepts, a larger proportion of system operating costs is associated with handling minimum-equipped aircraft operating in mixed airspace or in airspace in the vicinity of high-density terminals. Conversion to a fully cooperative system, where each aircraft would be equipped to respond to interrogation by the data-acquisition system with sufficient data that its position could be determined to the required accuracy, appears to offer large potential savings and significant improvement in system performance. In addition, a message exchange capability, ground-air-ground, would be provided with only that sophistication required in each aircraft for the class of service desired (e.g., VFR, IFR). There appears to be the possibility that this type of system would permit most of the primary radar systems to be decommissioned with a substantial reduction in total system cost.

The increasing number of near midair collisions resulting from the increasing density of air traffic in hub areas is causing the establishment of Terminal Control Areas, which require users to have a minimum airborne equipment complement. Studies of future traffic growth indicate an increasing need for additional capability to permit the ATC system to exercise separation control over all aircraft operating in high-density areas to maintain air safety at a reasonable level (ref. 2). The Intermittent Positive Control System represents a way of meeting this need and requires users to have a minimum airborne equipment complement based on expansion of the present beacon system and incorporation of a data link function and collision-avoidance indicator in the cockpit. With such minimum equipment on all aircraft, the need to increase the extent of positive control areas can be minimized.

Forecast general aviation growth indicates that more than half of general aviation activity will be located in hub areas by 1980. Aircraft based in these areas would be equipped to

respond to IPC. In addition, other traffic would be subject to IPC when visiting hub areas. If the remainder of the air fleet were equipped with the minimum cooperative equipment, appreciable savings could result and improved service rendered to the users of the airspace.

Recent studies of a model of an all-cooperative system indicated that a substantial reduction in total system cost could be achieved. The system model studied assumed a starting date of 1980 and was based on retaining 56 radars at the medium- and high-density terminals to provide adequate backup for cooperative equipment failure. In Table 4.2, various funding alternatives are examined to evaluate their benefit (saving)-to-cost (Government and user) ratios.

Figures 4.14, 4.15, and 4.16 illustrate the cumulative savings that accrue by reducing the size of the radar plant, costs to the user, and the excess of benefits over cost for Case III. The upper line in Figure 4.14 shows the approximate cost of continuing to upgrade, expand, operate and maintain the present primary radar system. The lower curve starting in 1980 indicates the same costs for the 56 terminal radar systems that are retained and the area between the lines indicates the savings that accrue through reduction in the size of the primary radar network. Figure 4.15 shows the cumulative costs for equipping 30% (related to aircraft voluntarily equipped), 60% (relates to aircraft based in hub areas), and 100% (relates to aircraft equipped in a fully cooperative system) of the general aviation aircraft. The difference between the 30% curve (actual percentage varies with the year) and the 100% curve is the added cost to the user of an all-cooperative system. Figure 4.16 shows the cumulative difference between user costs and Government savings based on a system start time of 1980.

The potential reduction in overall system cost that could be achieved by requiring each aircraft to be equipped with at least the minimum cooperative device is highly dependent on policies that facilitate airborne equipment implementation. The cost savings that can be achieved and the length of time taken to increase system capacity are directly dependent on the rate at which airborne equipment implementation takes place.

TABLE 4.2. COST/BENEFIT RATIOS, FULLY COOPERATIVE SYSTEM

		BENEFIT/COST RATIO[a] (BASED ON 1970 DOLLARS)
CASE I	USERS PAY ENTIRE COST OF EQUIPMENT. (GOVERNMENT SAVINGS-TO-COST RATIO)	10.52:1 (8.50:1)
CASE II	GOVERNMENT FURNISHES NEW IPC BEACONS ONLY TO SINGLE-ENGINE GENERAL AVIATION USERS AT NO COST.	2.45:1 (1.36:1)
CASE III	PRESENT LEVEL OF VOLUNTARY EQUIPPAGE CONTINUES (ABOUT 30%) GOVERNMENT FURNISHES NEW IPC BEACONS AT NO COST TO REMAINDER.	2.65:1 (1.5:1)
CASE IV	GOVERNMENT PAYS $700 OF COOPERATIVE EQUIPMENT COST TO ALL SINGLE-ENGINE GENERAL AVIATION USERS.	3.56:1 (2.11:1)
CASE V	GOVERNMENT FURNISHES NEW IPC BEACONS TO ALL GENERAL AVIATION USERS AT NO COST.	2.1:1 (1.16:1)

[a]*Actual or budget dollars were used to determine savings-to-cost ratios. Numbers in parentheses indicate the ratios derived using discounted dollars (10% annual rate).*

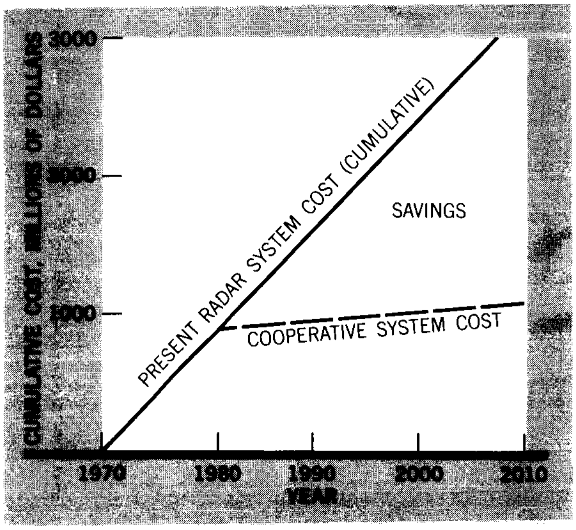

Figure 4.14. Primary radar cost.

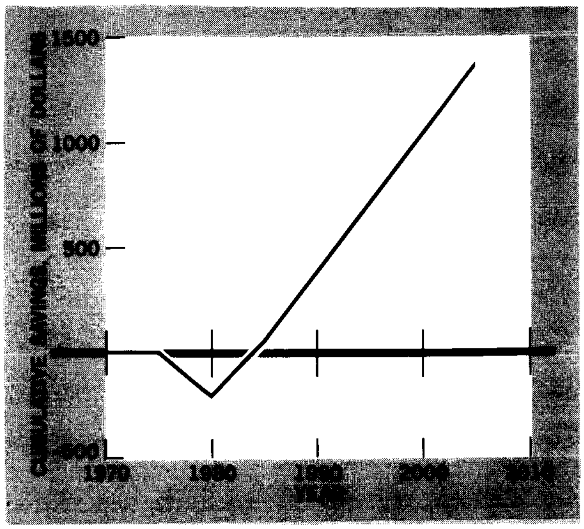

Figure 4.16. Cumulative savings less Government and user costs.

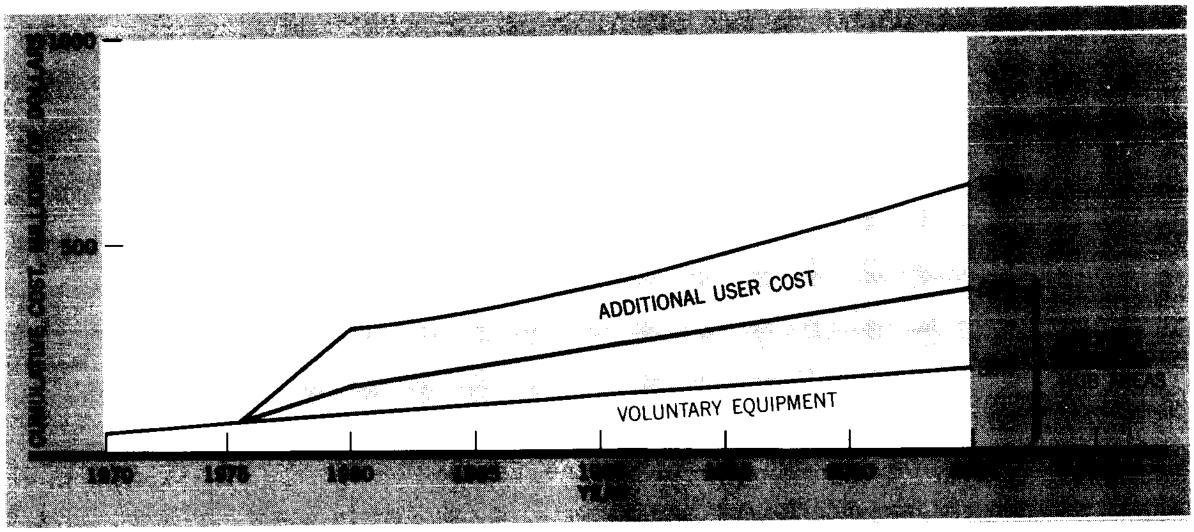

Figure 4.15. User equipment costs – IPC transponder.

Summary

The above policies provide the basis for early implementation of a system that can meet the growth and safety requirements. They also include the mechanism for achieving substantial reductions in system cost. Without policies of this type, implementation times will be substantially increased, perhaps by as much as 10 years, and system performance, efficiency, and safety will be compromised.

CONCLUSIONS

Early growth in system capacity depends on prompt increases in R&D levels to permit expediting the implementation of the recommended short-term improvements. Supporting policies relative to airspace use and airborne equipment improvements and installation are needed. A cooperative system requiring all aircraft to carry minimum equipment would accomplish substantial system cost savings and facilitate system

implementation. The cooperative system should be achieved as early as practicable, preferably by 1980.

Capacity increases and improvements over the long term require a new system concept and the exploitation of new technology. If this approach is taken and the system progresses in an evolutionary manner toward incorporating new control concepts, the forecast of growth needed in airway system capacity can be met at least through the turn of the century.

REFERENCES

1. Airport and Airway Development Act of 1970, Public Law No. 91-258. 91st Congress, 2nd Session, May 21, 1970.

2. Report of Department of Transportation Air Traffic Control Advisory Committee (2 Vols.). U. S. Government Printing Office, Washington, D. C., December 1969.

3. The National Aviation System Plan, Ten-Year Plan, 1971-1980. Federal Aviation Administration, Department of Transportation, Washington, D. C., 1970.

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AIRPORTS

INTRODUCTION

This section covers the airport factors that influence the air transportation system on the ground:

- Airport airside – that which primarily supports the movement of aircraft (airfield area).
- Airport landside – that which primarily supports the movement of people and goods (terminal area).

Airports divide naturally into two principal elements, the airside and the landside. The demarcation between the two is at the gate at which passengers enplane or deplane or the point at which cargo is loaded or off-loaded. The landside may be further divided into segments at the points where passengers or cargo enter or leave available ground transportation. The segments and their functions are shown in Figure 4.17.

This relatively simple arrangement works satisfactorily only when all elements of the airport are in balance, that is, when the flow across all interfaces is approximately equal. When there is an imbalance in the elements of the airport and one or several elements are saturated, relatively minor delays can cause major disruptions of traffic. Temporary delays caused by weather or by equipment failures quickly clog the traffic inflow from the landside. Unexpected or unplanned arrivals of several wide-body large-capacity aircraft at the same time create wall-to-wall jamming in terminal buildings and chaos at the curbside.

Critical difficulties are arising because airport development and ground-transportation facilities have lagged far behind vehicle development. Intensive aeronautical research and development have made possible aircraft whose size and performance are well beyond the handling capabilities of present airport-landside facilities.

THE CURRENT SITUATION

There are 817 airports in the United States that provide certificated airline service. The total number of aircraft landing facilities, however, (including airports, heliports, and seaplane bases) is about 11,200 of which 6,913 are privately owned and 4,252 are publicly owned; 3,504 have lighted runways; 3,733 have paved runways (only about 55 of these are more than 10,000 feet long); 244 have a Category I Instrument Landing System (ILS) (31 have two ILS runways); 126 are radar-equipped medium- and high-density terminals; 161 are tower-equipped lower density terminals; and 47 have combined flight service station towers.

Approximately 3,200 of these facilities, including the 817 used by certificated airlines, have been identified as essential to the Nation's air transport system and thus are included in the FAA's National Airport Plan (see Table 4.3 and ref. 1).

Four of the Nation's major airports are at peak-hour saturation, not only in terms of the number of aircraft they can accept, but also in terms of demand on terminal-building facilities, automobile parking, and airport access. To complicate the problem further, competition for available land and funds in large urban areas where airport congestion is more severe, coupled with environmental and jurisdictional problems, have in many cases seriously delayed development of badly needed new airport facilities.

Additional landing facilities are needed to meet current and future demand; more than 1,200 additional airports (the majority for general aviation) are identified in the FAA's 1971 National Aviation System Plan (ref. 2) as needed to meet the 1981 aviation demand requirements. An increase in the total number of landing facilities, however, does not necessarily mean better transportation service nor does it assure increased capacity where it is vitally needed.

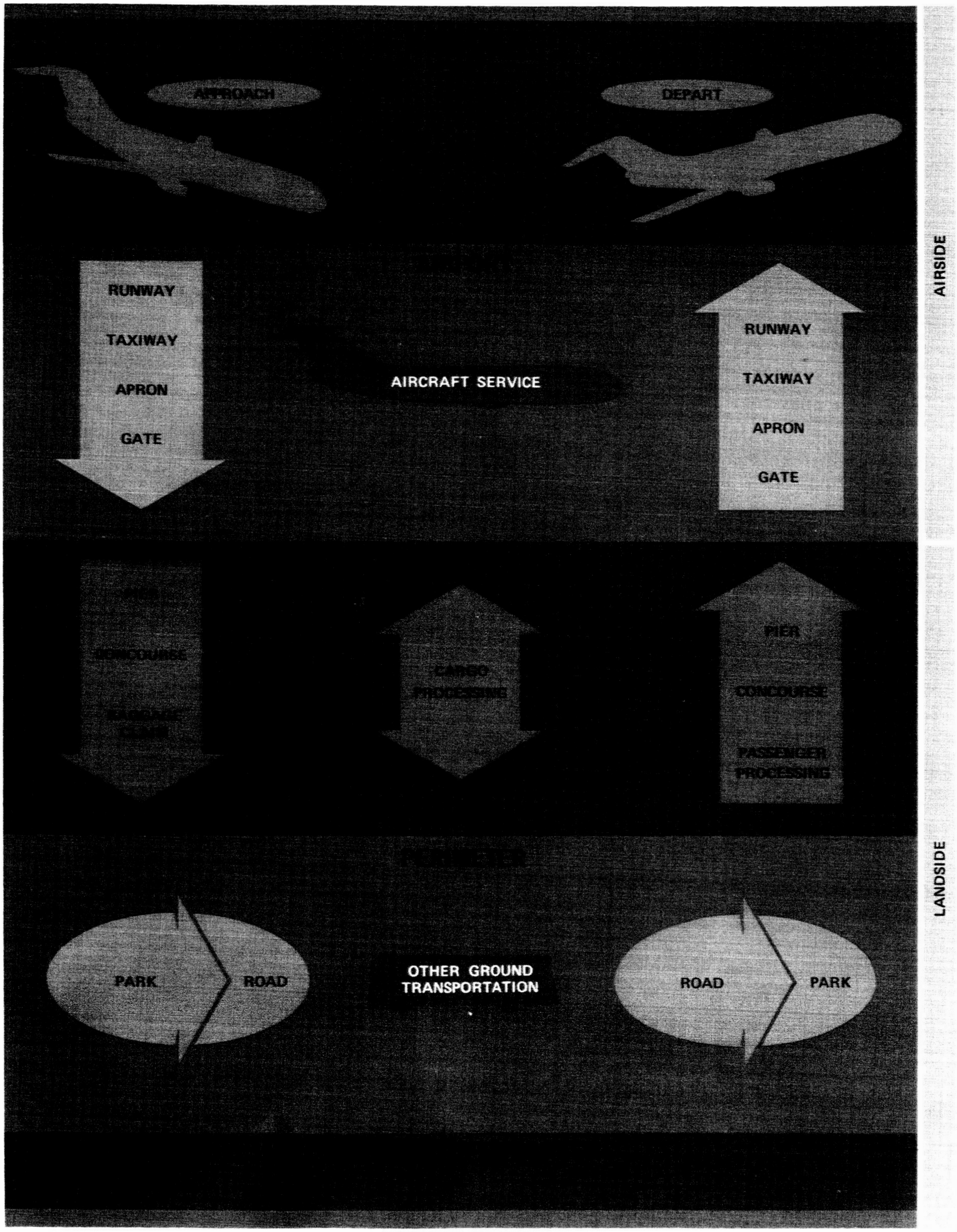


Figure 4.17. The airside and landside segments of the airport.

The present inadequacies of some major airports relate in part to the manner in which they have developed. Past development has tended to concentrate commercial passenger operations at a few major airports in each urban area. The result has been saturation of the airport, airway, terminal, and access/egress system (the complementary ground transportation). If the historic growth trend continues, the existing problems will be further aggravated. As airport activity grows, supporting services saturate, access-road congestion increases, and passenger delays for the trip to and from the airport increase. To provide an effective air transport system, instead of larger airports (toward which there is currently a trend), a more effectively distributed system of airports tailored to specific user needs is required – a system that can grow with demand. This will take time and it will undoubtedly be necessary to increase capacity at existing airports until a new airport plan has been developed and becomes effective.

It is clear that demands on the airport system in 1975 to 1995 cannot be met simply by the construction of additional runways and airports based only on current design standards and processing methods. Some airports must be designed for location closer to major population or activity centers, where provisions for intraurban transportation can be provided efficiently and at low cost. Airport design must be specialized for particular vehicle types, such as STOL and VTOL, or for a particular type of service, such as large CTOL regional passenger jetports, general aviation, training, or test facilities, or possibly for special-purpose cargo airports, or for specific mixes of vehicles and functions.

TABLE 4.3. NATIONAL AIRPORT SYSTEM REQUIREMENTS, 1972–1981

SYSTEM CLASSIFICATION	CURRENT SYSTEM OF AIRPORTS	PROJECTED SYSTEM ADJUSTMENTS		PROJECTED 1981 NATIONAL SYSTEM
		SYSTEM ADDITIONS[a]	INTRA-SYSTEM CHANGES	
PRIMARY SYSTEM				
HIGH-DENSITY	11	12	+ 20	43
MEDIUM-DENSITY	13	5	– 2	16
LOW-DENSITY	6	2	+ 6	14
TOTALS	30	19	+ 24	73
SECONDARY SYSTEM				
HIGH-DENSITY	32	24	+ 96	152
MEDIUM-DENSITY	178	135	+147	460
LOW-DENSITY	162	46	– 30	178
TOTALS	372	205	+213	790
FEEDER SYSTEM				
HIGH-DENSITY	98	70	+573	741
MEDIUM-DENSITY	1,287	345	+120	1,752
LOW-DENSITY	1,451	588	–930	1,109
TOTALS	2,836	1,003	–237	3,602
NATIONAL SYSTEM				
TOTALS	3,238	1,227	0	4,465

[a]Includes new airport construction requirements and the privately and publicly owned airports that will be added to the national system over the 10-year period. Source: Ref. 2.

Until recently, Federal involvement in civil airports was directed primarily toward public safety, and toward fostering civil aviation through financial assistance in construction and expansion of airport airfield facilities. Guidance and advisory services have been provided by the Federal Government to airport owners, builders, and operators. There is a Federal interest in siting of airports to enhance efficient and safe usage of the airspace. There is also a requirement that the civil airport system be developed with sufficient capacity to operate as a balanced element of a national air transport system that complements and supports, rather than constrains, the air traffic control system.

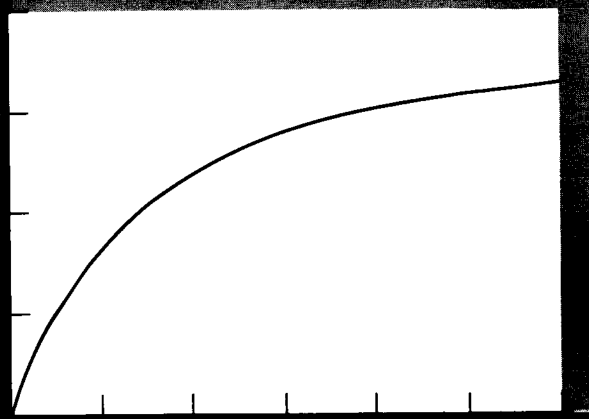
Unfortunately, limited Federal interest in the past has helped create an imbalance of airport capacity. This limited interest resulted in a paucity of assistance and guidance for the development needed in the airport's terminal area to produce a viable and balanced total airport complex.

The crux of the problem lies in the lack of a total systems approach to airport planning and development. With only a few exceptions, airports in the United States are owned, operated, and maintained by a multitude of local authorities. Often the airport's major approach and departure paths pass through areas outside the political jurisdiction of the user community. Although this diversity of ownership has been regarded as socially and economically desirable, it unquestionably has complicated the standardization and balanced development of a national system of airports. In addition, the lack of an overall air transportation system plan, realistically defining the demands and characteristics of passengers and cargo and the interrelationships with other modes, contributes to much of the congestion that exists within the system today.

There are a few notable exceptions. The Minneapolis–St. Paul metropolitan satellite-reliever airport system is a result of Minnesota's decision 25 years ago to create a metropolitan airport commission with responsibility for the area's aviation needs. The objective was to provide general aviation facilities to relieve and supplement the major airline-served airport. This was accomplished by moving more than 75% of the general-aviation-based activity to the satellite relievers. Another exception is the Federal Government's Dulles International Airport that was planned and developed as a result of foreseen limitations of Washington National Airport. The latest airport design concepts of that period (1956 – 1958) were incorporated, including zoning restrictions, design for the rapid flow and processing of people, and provisions for high-speed access and egress.

New concepts now require extensive systems engineering, including simulation and demonstration projects, to determine not only their operational and economical feasibility but also their priority and trade-offs within the total system's development. Despite huge capital investments, airport authorities spend very little on research and development. Airport associations have not gathered technical people who could undertake such research, nor have they sponsored any significant amount of university research. With a few exceptions, these associations do not maintain planning staffs of any national consequence. Under these conditions, significant improvement is not likely unless the Federal Government shapes, guides, coordinates, and promotes the required national effort.

Airlines can acquire additional airlift capacity within about two years by initiating the purchase of in-production aircraft models. Manufacturers can produce improved aircraft in quantity in less than four years. Significant improvements in air traffic control now take a decade or more to become operational. The location and development of major new airports requires even more time. Thus, there is fundamental incompatibility in forward planning and phasing for the several elements of the air transportation system. Wherever possible, the overall planning should be paced by the progress of the leading element rather than geared to the pace of the slowest.



CUMULATIVE % OF PASSENGERS ENPLANED	CUMULATIVE NUMBER OF AIRPORTS	NAME OF AIRPORT
8.1	1	O'HARE
14.2	2	LA INT'L
18.9	3	JFK
23.5	4	ATLANTA
27.1	5	S.F. INT'L
30.7	6	LA GUARDIA
33.8	7	LOVE FIELD
35.9	8	NATIONAL
39.7	9	MIAMI
42.5	10	BOSTON
49.0	13	
51.1	14	
67.0	25	
71.3	30	
77.2	40	
81.5	50	
84.5	60	

Figure 4.18. Number of enplaned passengers, all services, total system operations, U.S. certificated route air carriers (excluding helicopters): 12 months ended June 30, 1969. *Source: Ref. 3.*

IMPACT OF GROWTH ON THE AIRPORT SYSTEM

An immediate problem is increasing the capacity of airport facilities that are at, or approaching, saturation. This must be done in parallel with the upgrading of all airports required in the national system. Passenger enplanements are expected to increase more than 2.5 times at 10–year intervals (1965–1975 and 1975–1985). The use of larger aircraft, however, should keep the increase in airport operations down to a factor of about two (a doubling of airport capacity at 10-year intervals).

Enplanements at certificated airports of the 60 largest air transportation hubs in this country (Fig. 4.18) comprise 85% of the U. S. total (ref. 3). Failure to meet the projected demand at these communities may compromise the growth of air passenger traffic and deprive the Nation of the benefits of flexible, fast, and economical air transportation.

At four key airports – Kennedy, La Guardia, Washington National, and Chicago O'Hare – user demands already exceed capacity. These airports operate under a quota system that limits hourly operation rates. Factors causing these restrictions include access roadway congestion, lack of auto parking facilities, limited airspace and holding patterns, limited runway capacity, lack of ramp space and gate positions, and required aircraft noise-abatement procedures. Unless substantial improvements are made, between 20 and 30 U. S. airports will reach this condition by 1980, and twice that many by 1995. Restrictions in airport operations impose losses on the community, both in service and in commerce generated or served by air transportation.

Any reduction in total trip time achieved in the airside (and airborne) segments of the overall system may be negated or lost without significant improvements in the airport landside (terminal area). The scarcity of space for almost any landside function creates long queues that can back up and cause malfunctioning in other airport operations and, by causing air traffic delays, cause departing aircraft to be held.

The predicted growth in passenger and cargo traffic through 1995 will also impose a tremendous strain on airport terminal facilities. Critical

problems are passenger-, baggage-, and cargo-handling, automobile parking, and curb space.

Airports for the 1975–1995 period will require extensive new access systems to handle peak movements of people and goods. Traffic at the busiest long-haul CTOL airports in 1985 is expected to approach 100 million passengers per year. Estimates for the future busiest STOL and VTOLports range from 5 to 10 million passengers. The largest air transportation hub in the Nation may well consist of three or four long-haul airports and 10 to 20 short-haul airports. Two aspects of an access/egress system must therefore be considered: the requirements at each airport; and the total system for providing efficient intra-city airport access. Further discussion of airport access/egress will be found in the section on "Complementary Surface Transportation."

SHORT–TERM CONCEPTS AND BENEFITS – PREVIOUS STUDIES

Increasing the capacity of existing airports for aircraft, passengers, and cargo appears to offer the optimum near-future solution for most major community airports. Political problems, high costs, ground-transportation limitations, and airspace restrictions involved in the establishment of new airports, plus increasing costs of land around existing airports, inhibit other solutions. Despite public opposition to the noise generated by aircraft operations, land value tends to increase around an airport because of its desirability as a focus for business activity. Land costs alone can amount to $500 million for a 20,000-acre plot as acreage approaches $25,000 per acre (Fig. 4.19), while land values around the busiest airports are typically $50,000–$100,000 per acre and more. It will take time to investigate such new concepts as satellite (remote) terminal facilities and special-purpose cargo airports.

The Air Traffic Control Advisory Committee (ATCAC) (ref. 4) recognized the difficulty of obtaining new airport sites in the vicinity of major urban areas and noted in its report that short-term gains in capacity must be achieved through expansion of existing capacity.

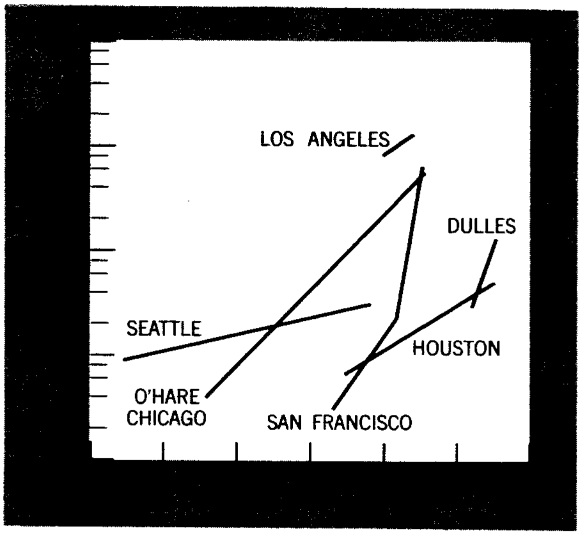


Figure 4.19. Increases in land value around U.S. airports.

The Committee concluded that runway capacity could be increased 2.5 times by replacing the present single runways with dual runway systems. The runways, one for landing and one for takeoff, would be separated by 700 feet. Although the runways would be operated interdependently, the interaction between arrivals and departures would be much reduced compared to the present system. Replacement of the runway by itself, however, provides only a 40% increase. To achieve the full potential of any new runway, it will also be necessary to replace the present instrument landing system with a microwave scanning-beam system that does not suffer from reflection problems, to provide computer control of aircraft spacing, to implement a wide-band digital data link from the ground system to the airborne system, and to eliminate or counteract trailing wing-tip vortices (ref. 4).

Further increases in capacity could be achieved if runway spacing for simultaneous instrument landings was reduced from the present 5,000-feet separation to 2,500-feet separation. This would permit installation of additional runways adjacent to or between existing parallel runways at some airports.

Increasing aircraft operations could greatly accentuate the existing noise problem unless positive measures are taken to reduce the approach and departure noise. The Committee recommended, therefore, that approach and departure routes be designed to route aircraft over water and over unpopulated areas wherever possible. Implementation of a recommended curved approach/departure route system would require development of an airborne computer utilizing the signals radiated by the microwave scanning-beam landing system. Other recommendations aimed at reducing noise included runway relocation, noise-abatement procedures, and installation of quiet engines on all jets. An analysis of Kennedy airport indicated that implementation of these procedures could possibly reduce the area exposed to noise annoyance by 75% (ref. 4).

EVALUATION OF FUTURE SYSTEM ALTERNATIVES

Although expansion of existing airports provides much of the needed short-term gains, longer term capacity growth must be based on distributing traffic to additional landing sites. This is partly because of limitations on real estate available near the major airports and partly because of saturation of the local access/egress system. At some traffic densities, the gain to be achieved through expansion of an airport is offset by a generalized loss of efficiency. Although the point at which this occurs has yet to be determined, alternative solutions are required no later than the 1980's.

Alternatives to permit further growth include the shifting of cargo- and passenger-processing facilities to off-airport locations, establishment of special-purpose cargo or cargo/general aviation airports, building of regional airports away from large urban areas, creation of STOL and VTOLports, and development of additional facilities for general aviation.

Transfer of passenger- and cargo-processing facilities to off-airport locations could release land needed for other airport operations. The extent to which this alternative should be pursued would depend in large measure on the availability of additional land at each location.

Improvement is also needed in the processes for handling cargo and passengers. Within the terminal area itself, the passenger must move through a series of loosely integrated processes – ticketing, baggage checking, movement to the gate, seat selection, and boarding. These steps are not only time-consuming to the traveler but costly to the airline since a number of people are involved. Today it costs up to $15 to get one passenger boarded, posing a fruitful area for future R&D.

Passenger and cargo processing steps lack balance. Delays often occur at the interfaces between the systems elements, which lengthen the door-to-door trip time. Many of the delays experienced in cargo-handling are due to regulatory barriers, different documentation practices, and lack of intermodal standardization of such things as cargo containers. Lack of standardization in baggage handling of the travelers also results in poorer service to the patron and greater operating cost among the airlines, as the carriers are not taking full advantage of the economy of scale that standardization can offer. The terminal area is one of the most visible parts of the aviation system to the traveler – it is believed that balancing the many processing steps in the terminal will stimulate even greater use of air travel when improvements in passenger-handling efficiency become evident to the patron of the system.

Present baggage and cargo handling methods on the ramp also contribute to congestion. In 1969, about 70% of the cargo capacity of U. S. airlines went unused. The 30% that was used contributed 15% of the airlines' total revenue. As wide-body jets increase in number and belly capacities correspondingly increase, there will be even greater pressure to utilize this unused capacity. Cargo-carrying surface vehicles and handling equipment will contribute to more and more congestion at the loading ramp as cargo capacities are utilized, accentuating the need for greater automation.

Special-purpose cargo airports could greatly expedite handling of "nonbelly" cargo and increase to some extent the passenger-handling capacity of some major airports. All-cargo aircraft operations are commonly conducted in off-peak hours, except where prohibited by late evening noise-curfew restrictions. Two gains of moving cargo operations and facilities to independent airports would be the release of land at major airports to other operations and the reduction of highway congestion because of local freight-transfer operations. This approach, however, raises a question on optimum transfer methods for "belly-carried" freight.

Another approach, involving the use of V/STOL vehicles, would offer some major relief to the existing major airports. The V/STOL systems should permit reduced total trip time for passengers traveling relatively short distances – less than 500 miles. To be effective, these systems must have STOL and VTOLports located close to the potential user's origin and destination, which would often be a city's central business district. The STOL and VTOLports may, therefore, be located in both outlying and downtown areas to meet the transportation objectives of the system (see the "Short-Haul System" discussion in the "Missions" section). Each STOL and VTOLport would have the potential of handling approximately 5 to 10 million passengers annually compared with perhaps 100 million passengers for a major urban CTOL airport. Thus, a system of STOL and VTOLports could be effective in relieving the load at major airports and reducing door-to-door travel time for relatively short trips.

ENVIRONMENT

Environmental considerations will play a critical role in future airport system development. Effort must be directed toward solving system-capacity constraints such as noise and safety hazards, including wake turbulence and weather.

Possible noise remedies include improved sound barriers and structural soundproofing of buildings in the airport vicinity, changes in land use, changes in locations and configurations of airports, and special operational procedures at airports. Studies to date indicate the need for more refined noise-impact criteria and noise-impact analyses for each proposed airport location.

Current procedures for minimizing the adverse effects of aircraft wing-tip vortices, hazardous to other aircraft operations, may well become ineffective as larger aircraft and more V/STOL types come into use. Continued study must be conducted toward economical and operationally feasible systems to detect and dissipate aircraft vortices.

Increased all-weather utilization of airports under Category III operation will increase the pressure for more effective snow-removal techniques. The FAA is investigating snow-removal methods, including airborne techniques and in-runway heating systems. Studies are also under way to develop techniques for describing weather conditions by automatic means. It is possible that applied R&D might produce schemes for weather evaluation and control for use at airports within a few years.

Control of birds around runways is another airside problem that requires continuing R&D. Current FAA studies of bird strike statistics and migratory habits are under way to assist in the development of procedural avoidance techniques. It is important to evaluate the effects of noise and pollution on animal and plant life as well.

Present FAA R&D requirements also include the need for developing additional and updated information for airport operators on fire-fighting agents, equipment, and techniques, including the use of air-cushion vehicles and helicopters for fire-fighting and rescue.

An R&D program is needed to develop techniques for assuring minimum restrictions on aircraft operations that involve minimum real-estate consumption and minimal environmental impact. This is the basic task of achieving public acceptance and support of airports. Problems encountered by the interstate highway system on

urban routings and by airport authorities in enlarging or adding to airports suggest that serious problems in intergovernmental relations require Federal support in operations research and planning.

Planning considerations for airports are numerous and complex, yet few quantitative systems engineering approaches have been developed to assist in the planning and development of airport and terminal facilities.

TECHNOLOGY

In the past, major technological advances in civil aviation have been achieved with air vehicles rather than the airport and its operating environment. Technology, however, has had a major effect on the direction of the airport program. A major problem affecting airport system development is aircraft noise. There is little question that many communities have reached their noise-tolerance level. Success in reducing noise at its source – the air vehicle – will have a most significant influence. The short-term improvements defined by ATCAC include measures to reduce noise. Beyond this point, however, mechanisms such as a Federal airport development land bank to provide buffer zones around airports or regulations to define noise-compatible land use may be required to permit further expansion. The problem becomes more critical for proposed downtown STOL and VTOLport locations. The practicality of early establishment of downtown STOL and VTOLports is highly dependent on the availability of water areas or noise-tolerant industries close to the desired STOL or VTOLport locations. Realization of the potentials of elevated and off-shore STOL and VTOLports will require additional R&D.

Optimum location of airports cannot be determined without extensive systems analyses, including considerations of community impact, and trade-offs between proximity to population centers and time savings to be gained through effective high-speed ground transportation, intra-urban air movements, or other access/egress methods. The systems analyses must be complemented by an equally systematic approach to the institutional (social, political, and financial) problems involved.

There is a need to analyze airports in the broadest systems context, considering the total airport and its interfaces with the air traffic control system and the surrounding community. Analyses of aircraft, flow of passengers and cargo, ticketing, documentation, baggage-handling, access/egress, and other airport processes (see Fig. 4.17) must be treated together in the design of compatible facilities and operations.

POLICIES

Policies for an adequate and safe national system of airports should supplement the Airport and Airway Development Act of 1970 (ref. 5), and provide the basis for defining and implementing the required increase in airport capacity. The policies should extend Federal responsibility and assistance in the areas of airport planning, implementation, design, and access/egress system interface.

The Federal role in the planning and development of airports has been reasonably successful within the scope of available resources, legislative authority and responsibility, and the aviation environment during the 15 years after passage of the Federal Airport Act of 1946. (Total Federal funding under the Federal-Aid Airport Program amounted to $1.2 billion from inception in 1946 to termination on June 30, 1970.) However, the growth rate of aviation and changes in other factors affecting airport-development needs led to problems whose solutions were beyond the scope of the Act (ref. 6).

The Airport and Airway Development Act of 1970, in addition to its provision for an airport airfield development grant-in-aid program, also authorizes the Secretary of Transportation to grant funds to planning agencies for airport system planning and to public agencies for airport master planning. This new program will greatly

assist individual public and private planning agencies in locating and developing airports more effectively and, it is hoped, lead to a more adequate national airport system. However, it does not by itself provide the guidance and resources required to develop the Nation's airports as a total system. Although the Act authorizes the use of assets from the user-charge trust fund for airways research and development by the Federal Government, no such provision is included for airports. The determination of need and the siting of new facilities to accommodate forecast demand compatible with their functional role and environment require both quantitative and qualitative analyses (ref. 5).

Demand forecasts for general aviation, air carriers, and the military must be studied and catalogued to provide a data source for use in determining service requirements. Improved forecast methodology must also be provided to State and local officials and airport managements for determining the airport's land requirements and facility needs, considering the effect of air vehicle types such as STOL, VTOL, and supersonic transports.

Analyses must be made of technological changes, and guidance provided on how these changes can be included in the planning process. Growth and development patterns of critical airports and air corridors must be analyzed to study the dynamics and problems associated with regional, State, or metropolitan area air transportation systems. Analytical and simulation capabilities must be developed to predict and test the consequences of network expansion strategies and to determine total capital requirements.

It is primarily in the area of a total systems approach to airport planning and development, and in the development and provisioning of planning tools and guidance, that the Federal Government can contribute most effectively to solving the problems of airport congestion, design configuration, ground control and guidance, environmental considerations, and passenger/cargo handling.

Federal leadership will be needed to achieve a long-range national airport system plan that will effectively define aviation's role in meeting overall transportation requirements, and in stimulating growth in some areas. The goals and objectives of the national transportation system must be translated into a plan that defines the anticipated growth for each area, selects among alternatives for meeting this growth, and works with the local airport administration to develop the overall plan. The Airport and Airway Development Act of 1970 requires that a National Airport System Plan, which accomplishes the above, be published by May 1972.

The foregoing actions alone will not suffice to increase capacity even though they should clearly establish the air transport and airport requirements for each area. Implementation of the plan places the dual responsibility on the Federal Government to conduct the research and development necessary to make the airport an "acceptable neighbor" and also to develop the mechanisms needed to aid local administrations in land acquisition, airport development, and access/egress system development. This responsibility should also encompass the establishment of additional funding policies to support land acquisition for future airport needs in much the same manner that Federal assistance is given to purchase land for future parks and recreational areas.

A third area in which the Federal Government needs to provide leadership is in the development of improved designs for terminal facilities. Up to this time, such development has been the responsibility of local airport authorities and users. Much improvement in the efficiency of land use and in speed of handling passengers, cargo, and baggage can be achieved by using a systems approach to the development of a "terminal system." The present approach encompasses a variety of subsystems operating independently. The result is a continual degradation in terminal efficiency.

The above concepts suggest the steps necessary to meet future airport demand. None will be

truly effective, however, until the Federal Government has developed an effective long-range national airport system plan and assures its timely implementation.

This suggests another policy area in which the Federal Government could contribute more effectively to long-range airport system development. Under the present Airport Development Aid Program established by the Airport and Airway Development Act of 1970, the FAA and DOT have contractual authority to enter into grant agreements with airport sponsors for periods of up to three years only. As a result, many airport sponsors are either unable or reluctant to undertake long-range development because of the uncertainty about resources that will be made available under this program.

If the contract authority of the FAA and DOT under the Airport Development Aid Program could be extended to the full term of the Act (10 years), annual appropriations would then be required only to liquidate obligations incurred for airport development – with the major advantage of providing a more stable development-planning base for airport sponsors. Although the Act recognizes the merits of contractual authority to cope with the long-range development needs of the system, equal recognition should be given this requirement by the Executive Branch of the Federal Government so there will be no question as to the accomplishment of needed development within a prescribed time frame.

The Airport and Airway Development Act of 1970 also authorizes the Administrator of the FAA to establish minimum safety standards for the operation of airports serving air carriers certificated by the CAB. The development and establishment of certification criteria should be based upon a coordinated R&D program designed to insure that such criteria are reasonably valid and necessary to assure safety in air transportation.

MAJOR R&D REQUIREMENTS FOR AIRPORTS

The broad R&D requirements for airport system improvements that must be implemented over the next 10 years to meet future demand include:

- *System Engineering, Simulation, and Trade-off Studies.* The development and evaluation of new concepts for airports, concepts for expanding existing airport system capacity (e.g., special-purpose cargo airports, off-shore airports, STOL and VTOLports), improved terminal design, improved cargo-handling methods, and new approaches to the access/egress problem.

The systems approach would include the development of models to study the flow of passengers and goods through various types of airports to permit testing and evaluating various design options and optimum levels of activity; the development of techniques and criteria to predict the need, proper location, and timing for new airports in the system to provide for airport facilities when and where needed; the identification and development of decision criteria on trade-offs affecting the external design of airports for the interface with the vehicle, the airways system, and access/egress to the intermodal system(s), to provide the proper airport functional design as part of an integrated transport system; and the designation of airports that can be used as research and development test facilities to test and evaluate future system concepts and techniques (i.e., runway/taxiway design configurations, safety equipment and techniques, passenger/cargo processing devices, weather-control techniques, etc.).

- *Airport Airside (Airfield).* The development of a high-capacity runway-taxiway configuration, pavement design and testing, development of an automated

surface- and ground-control system, criteria development for off-airport construction, wake-turbulence detection and dissipation, improved terminal-weather forecasts, fog dispersal, and improved methods for clearing runways, reducing airport noise, and handling accidents.

These would include the development of ramp/gate criteria and design guidance to optimize time and cost factors; the development of guidance methods and equipment to improve aircraft servicing at the gate, to reduce noise, pollution, turnaround time, and vehicle count; the development of new or improved techniques and materials for elevated and off-shore STOLport construction, maintenance, and operational effectiveness; and the development of ground-based safety-support systems (fire-fighting, lights, arresting gear, crash, and rescue) that could be pilot-activated at both attended and unattended facilities.

- *Airport Landside (Terminal Area).* The improvement and development of passenger-, cargo-, and baggage-handling techniques, development of terminal-flow simulation and analysis models, investigations of off-airport systems for handling passengers and cargo and cost-effectiveness analyses of alternatives, and participation in the planning and conduct of model demonstrations or appropriate general-purpose system simulations.

The benefits sought through research are minimizing passenger- and baggage-processing time at the airport by providing appropriate terminal-area-design guidance; shortening total portal-to-portal time of both passengers and cargo; and reducing total real-estate requirements of the airport.

- *Airport/Community Access and Egress.* The development of improved methods of forecasting demand for passenger-, cargo-, and baggage-handling service requirements, and development of improved methods and techniques for handling large traffic flows.

The research would include the identification and development of methods for determining access/egress capacity, and criteria to select appropriate system(s) to provide airport authorities with economic and technical criteria upon which selection(s) can be based; and participation in the planning and conduct of demonstration programs and projects.

- *Regional Area Planning.* The development of long-range models to evaluate the effectiveness of totally new air transport system concepts and the generation of planning criteria for airport development.

This would include the development of planning methods to determine total regional air transportation demand as a quantitative basis for planning new or expanding existing airports and for determining distribution of demand within the region; and the investigation and identification of approaches and procedures to implement airport plans through cooperation and coordination with State and local authorities to maximize the possibility of timely system development.

It is clear, however, that airport congestion problems (primarily within the terminal area and access/egress systems) and environmental constraints (such as noise, wake turbulence, and weather) hindering system capacity expansion today should be given priority consideration.

OTHER REQUIREMENTS

Because data are lacking on some of the problem areas that cause congestion, selected demonstrations are recommended so that systems choices and their alternatives can be more clearly understood. The Federal airports (including NAFEC, and Edwards AFB), and, if needed, several commercial airports should be designated

demonstration airports as sites for both market and operational experiments. Some recommended experiments include:

- Off-site passenger and cargo processing.
- Integrated passenger processing.
- Runway/taxiway design and ground control of aircraft.
- Premium-rate landing fees for prime time at congested airports to level traffic load.

Edwards AFB could be effectively utilized to demonstrate the operational feasibility of runway and taxiway layouts as they may be affected by the characteristics of the aircraft and the terminal approach control system and of automated ground control concepts for aircraft. New runway and taxiway configurations could be inexpensively and quickly painted on the desert floor and tried with a minimum of effort. Once perfected, the experiment could be moved to NAFEC for further validation and eventually to a full operational trial at an operating airport.

Little data is presently available on the effect of altering landing fees and fares to correspond to level of demand throughout the day. A surcharge might be levied on landing fees, tickets, or both to determine if there were better techniques than the present ones to gain greater utilization of an airport throughout the entire day. There are proponents on both sides of this proposal as to the effect of such an experiment. Neither side has data to support its point of view, lending further weight to the need for such a trial. Vehicle development has utilized numerous demonstration techniques ranging from wind tunnels, proof-of-concept, to demonstrations in a "live" environment. Consequently, vehicle trade-offs are generally well-known. Airports have not taken full advantage of such a test approach. Thus, lack of accurate data has impeded innovations designed to relieve congestion in and around the terminal area.

DISTRIBUTION AND LEVEL OF R&D EFFORT

The airports R&D program recommended here is designed primarily to assist in the timely development and integration of airport planning and development required to anticipate and meet the needs of civil aviation with that of other national, State, and local land-use plans and transportation programs. The local socioeconomic and environmental factors that have a major impact in the planning and development processes are basically in the public interest. Only the Federal Government is in the overview position necessary to shape, guide, and promote the required national effort. Successful execution of the recommended program will require adequate resources – men, money, material, and time. A continuity of purpose must be provided so that the resources may be properly applied. Stability of R&D management must be maintained over the projected development period to assure timely and effective progress.

The total funding needed to support the airports R&D program is about $200 million over the next 10 years (ref. 7). The R&D program recommended represents only approximately 4% of the estimated total costs of the required construction and expansion in the airport/airside area in the United States over the same period.

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COMPLEMENTARY SURFACE TRANSPORTATION

INTRODUCTION

The time saving that is the main advantage of air transportation can easily be lost, as has already happened in some cities, by inadequate access/egress and complementary surface transportation. Much of the technological progress in air transport is being offset by a lack of corresponding progress on the ground.

COMPLEMENTARY SURFACE TRAVEL

As can be seen from Figure 7.3 in the "Benefits" section, between 1955 and 1965 increases in airplane speed brought about a significant reduction in the airborne portion of total trip time. The air travel portion of the trip has remained fairly constant since then. Except for flights using supersonic transports, the air time may not be expected to change markedly by 1985.

Unless remedial action is taken, however, the surface portion of total trip time may be expected to increase between 1970 and 1985, principally because of further deterioration of surface transportation.

Commercial air passengers normally move to airports today by highways (unlimited, limited, or exclusive access) and occasionally by rapid transit or elevated rail. The longevity and inflexibility of a fixed-right-of-way system precludes easy adaptation to the changing patterns in patronage characteristic of air transportation. Scattered origins and destinations usually do not have a sufficiently concentrated demand to warrant an exclusive service system.

Airport-destined travel is only a relatively small fraction of total urban travel. Surface-commuter peaks overlap airport-access peaks. To achieve overnight service, the delivery of air cargo shipments to the airport usually takes place at the end of the business day. It thus adds to the evening commuter-vehicle peak and to the evening passenger peak.

The highway and the automobile currently dominate airport access/egress, and, in the absence of any concerted counteraction, will continue to do so for the next two decades. The interstate highway system, now about 85% complete, has generally improved surface movement to and from airports. Completion of the remaining mileage may improve surface access to the airport in additional areas. Since highway usage is also expected to continue to rise, some of the anticipated gains may be short lived.

Airport access, in most cases a part of the urban transportation, is provided by local and State authorities. The myriad of political-jurisdictional entities at Federal, State, county, city, and borough levels impedes a smooth systems approach to the problem. The "gestation period" of planning and implementation is measured in terms of years. Progress of airport access is paced by the rate at which total urban transportation is improved. The rate depends on financing, community acceptance, planning, technological developments, and local politics.

When an access system is to serve the airport exclusively, costs are harder to recover and it is difficult to secure the allocation of local public resources to a system that appears to serve only a small part of the local population. An exclusive airport access system can usually be justified only to serve a new, very large airport located at a considerable distance from a large metropolitan area – for example, Dulles International Airport, serving Washington, D. C. Some communities, however, look upon the airport as a "profit center" that not only pays its way but materially contributes to the city's wealth, and might thus look more favorably on a system to provide fast and convenient access to the airport.

Economic viability also influences the availability of airport access. Public transit systems' operating revenues depend largely on high-peak

commuter traffic. Whether nonrush-hour utilization can be significantly increased through various incentive "gimmicks" may become a dominant economic factor.

Improved aircraft can be produced in quantity in less than four years. Substantial improvements in airport access systems, however, may well require a decade or more. Nontechnical (including political) factors stretch the total time beyond that required for construction – which in itself may be very lengthy. Ways must be found to accelerate the improvement of airport access at a rate compatible with air travel expansion.

Transportation regulatory agencies tend to discourage multimodal ownership by U. S. common carriers. Any intermodal coordination that takes place is voluntary. Incentives must be found if the different modes are to work better together. Almost by definition, intermodal connections fall into a "no-man's land." Even better would be a commitment by the airlines to undertake jointly a complete study of the portal-to-portal problem with the intent of actively participating in its solution. If this is to happen, encouragement must come from the CAB, the ICC, and local municipal regulatory authorities.

The Federal Government may be able to influence airport road access indirectly through its matching-fund mechanism. This works only when the local electorate approves the proposed project and the necessary funding.

One may foresee gradual improvements in urban mass transportation, in general. The San Francisco Bay Area Rapid Transit and the D. C. Metro projects should stimulate further development. When access to the airport can be provided by modest extensions of an existing urban system, economic operation of the airport runs may be possible (e.g., Cleveland Transit to Hopkins Airport).

AIRPORT LANDSIDE

Today's airports are mainly passenger/cargo collection and distribution systems to connect the urban transportation system to the aircraft boarding gates. These gates, usually numerous, are spread out along the airport terminal's ramp area. The urban transportation system has a much smaller number of connecting "gates" at the airport. Washington National Airport, for example, which is served by 24 airlines, has 41 aircraft boarding gates, but only 4 taxi loading stations, 4 limousine stations, 3 urban bus stops, and 3 rental car check-in points. The imbalance of public surface transportation, especially during peak hours, is readily apparent. It results in frustrating delays.

Another imbalance important to the time-limited air traveler who drives and parks his personal or rental car is the shortage or distant location of airport parking spaces. This method of ground travel is utilized far more than all the others (Fig. 4.20). The parking problem is perhaps the most critical one facing the landside of the airport today. It triggers a chain reaction of congestion that adversely affects the airport and the air traveler.

The airport serves also as an interchange point among airlines and between flights of the same airline. Extensive cooperation takes place among the airlines, and the needs of the air travelers are served to a substantial degree. Nevertheless, there exists a passenger-congestion problem which is obvious. The baggage problem has come painfully to the attention of some passengers. The transfer of interline baggage from one aircraft to another is a major determinant of the time aircraft must spend at the gates. It influences not only airline flight scheduling, but also the daily utilization of aircraft. It also has a strong influence on the number of gates required.

Usually, services within the airport's airfield-interface area are subjected to careful and vigorous planning by the airlines.

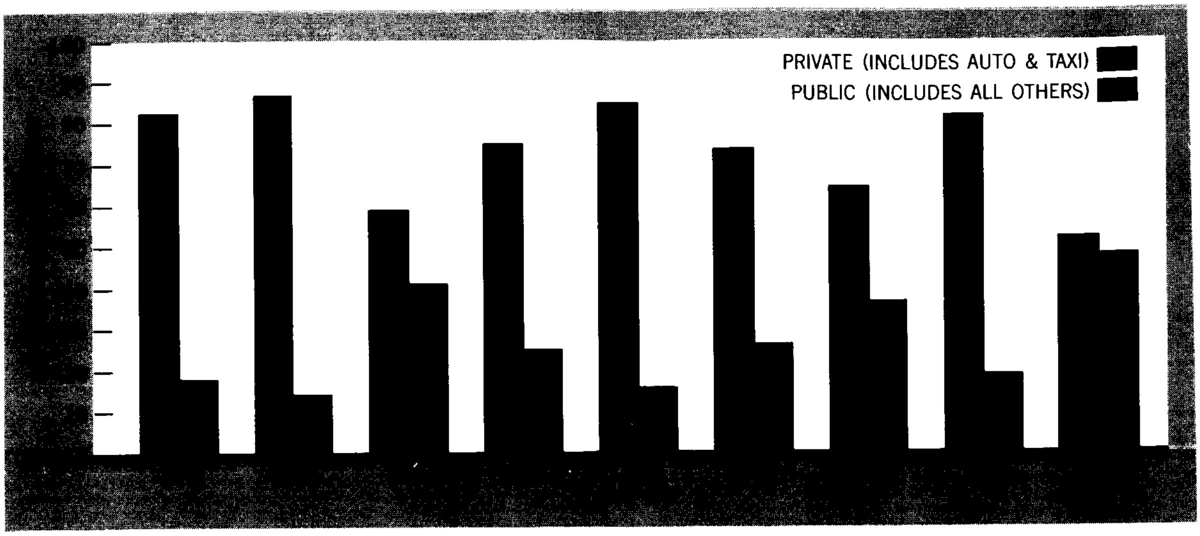

Figure 4.20. Air-passenger use of private versus public transportation, July 1967, by major airports. *Source: Ref. 1.*

TABLE 4.4. SUMMARY OF TOTAL ACCESS MOVEMENTS EXPECTED IN 1985 BY AIRPORT AND HUB TYPES[a,b]

AIRPORT TYPE	ANNUAL ACCESS MOVEMENTS, MILLIONS[c]					
	SUPER HUBS	LARGE HUBS	MEDIUM HUBS	SMALL HUBS	NON HUBS	ALL HUBS
AIR CARRIER						
DOMESTIC CTOL	349.2	–	–	–	–	349.2
INTERNATIONAL CTOL	524.7	–	–	–	–	524.7
DOMESTIC/INT'L CTOL (JOINT-USE)	–	650.0	592.8[d]	144.5[d]	73.0[d]	1,440.3
V/STOL	180.0	136.8	–	–	–	316.8
TOTAL	1,053.9	766.8	592.8	144.5	73.0	2,631.0
GENERAL AVIATION	81.9	68.4	66.3	85.0	8.0	309.6
TOTAL	1,135.8	835.2	659.1	229.5	81.0	2,940.6

[a]*Hubs are defined in "Systems Status and Potential" section.*
[b]*To include egress, double the number of access movements shown.*
[c]*Includes air passengers, meeters and greeters, employees, vendors, etc.*
[d]*Includes anticipated V/STOL operations.*

IMPACT OF AVIATION GROWTH

The expected growth of air passenger and cargo traffic will put a tremendous strain on airport access systems and their intermodal connections (see Table 4.4). An FAA forecast indicates that several of the largest airport hubs may handle more than 100 million passengers a year. An ATA forecast supports this estimate (refs. 2, 3). Airport peak hours (normally 7 to 9 a.m. and 5 to

7 p.m.) could produce an hourly traveler and visitor rate of 38,000. This peaking coincides with the day-shift movement of 10,000 or more airport workers, making a total surge of 48,000 people per hour.

Air cargo volume is expected to grow significantly during the next 20 to 25 years, generating by 1985 an average of 2 million tons annually at the major airports. If conditions do not change, truck traffic on access roads and at the airport will cause serious congestion. If no improvement is made in the manner in which truck capacity is being used today, during busy handling hours – which coincide with early morning and late afternoon passenger movement – some 2400 trucks per hour will be required. Even with cargo consolidation and other improvements in truck utilization, it must be expected that more than 400 trucks per peak hour will be required.

Today's intermediate-size airports (e.g., Phoenix, Indianapolis, and Orlando) may be expected to grow proportionately to demand, approaching the size of present-day large terminal facilities. Major airports are now generating ground-travel volumes equivalent to the central business districts of some fairly large cities. The ground movements at San Francisco International Airport, for example, equal those in downtown Phoenix.

Surface transportation for a busy short-haul airport should be less difficult to provide than for a busy long-haul airport, but both requirements are expensive to meet, particularly if the principal access is by auto and taxi. A future short-haul V/STOLport handling about 10 million annual passengers, for example, would require 10 city streets or more than 3 exclusive freeway lanes to accommodate the peak-hour movements without delays, whereas a future long-haul CTOL airport handling 100 million annual passengers would require 100 city streets or 33 exclusive lanes. The latter requirement would be so expensive and difficult to meet that it will undoubtedly impose a limit on the size of future airports. The V/STOLport may well require an associated 12,000 auto parking spaces, and the long-haul CTOL airport 120,000 spaces (almost 1.5 sq mi).

Most commercial air travelers arrive and depart from points other than the central business district.On the average, 60% of their trips begin or end at home, and only 25% begin or end at the central business district (refs. 1, 4). Airport ground travel has a widely spread pattern. Because of this, it has been unprofitable in most cities to develop a good public intermodal system. If the dominance of the automobile as a means to reach the airport is to be overcome, there must be a worthwhile incentive for the air passenger to use a public conveyance. It must be convenient, frequent, and dependable – not merely low fare. Each individual airport will represent a different planning problem.

Large metropolitan airports, from Boston to Norfolk, from Seattle to San Diego, and from Chicago to Pittsburgh, are major candidates for early complementary surface transportation planning and for its early implementation. Several planning groups are taking action to meet the problem. Financing appears to be a major obstacle in executing access and intermodal plans commensurate with the needs of the 1980-1990's. The problem is often complicated by the need to relocate a city's airport or to build an additional major airport. Popular concern over environmental effects has delayed a number of such decisions. Many decisions on airport location may have to be deferred for another 3 to 5 years. Such deferment contributes to growing congestion and to ground travel problems at already overtaxed municipal airports.

TECHNOLOGY AND FUTURE SYSTEM CONCEPTS

Planning and integrating complementary surface transportation with air transportation is an essential factor in solving some of the problems. The actual planning, financing, development, and operation, however, is the responsibility of local communities.

Assistance with complementary surface transportation is coordinated within the Department of Transportation by the Office of the Assistant

Secretary for Policy and International Affairs, the Urban Mass Transportation Administration, the Federal Railroad Administration, and the Federal Highway Administration. Their efforts are coordinated by the Office of the Secretary of Transportation. Each DOT entity, however, is primarily concerned with specific transportation modes – only secondarily with modal interfaces. The interfaces, as pointed out earlier, occur throughout the door-to-door trip. They tend to occur at the responsibility boundaries of different jurisdictions.

The Federal organizations involved are:

- *Office of High-Speed Ground Transportation (OHSGT).* This DOT office sponsors R&D in materials, aerodynamics, vehicle propulsion, vehicle control, communications, guideways and research testing on new systems, components, and techniques. It also provides for demonstrations to establish the contributions that high-speed ground transportation systems can make to more efficient and economical intercity transportation.

  Of the conventional systems, only high-speed rail service has reached the stage of full-scale intercity demonstrations. Experience with the Metroliners and Turbotrains has indicated that convenient and comfortable high-speed ground transportation can attract and keep increased patronage.

  R&D has also been undertaken to define promising new transport system alternatives. Research has focused on innovative systems able to reduce door-to-door time, largely through higher speeds.

  Systems intensively studied include the advanced monorail, the tracked air-cushion vehicle, the tube vehicle, the automated highway, auto-carrying pallet, and the autotrain. Some details of possible high-speed ground transportation alternatives are given in Table 4.5.

  Despite road congestion, accidents, air pollution, and its inefficiency as a carrier of large numbers of people, the automobile, more than any other transport mode, provides maximum flexibility for door-to-door transportation. The OHSGT is focusing emphasis on automobile transporters: the autotrain; small vehicles to carry single automobiles (a pallet system); hybrid air-cushion/wheeled buses capable of operating on guideways as well as roads; and guideways capable of automatic guidance and control of automobiles (automated highways).

- *Urban Mass Transportation Administration (UMTA).* In the 2 years of its history, UMTA has focused its research, development, and demonstration efforts on:
  - Circulation and distribution systems to move large numbers of people over relatively short distances in small, densely developed major-activity centers, with conveyor belts or moving capsules to carry several passengers with parcels.
  - Personal rapid transit systems that would extend over most of a metropolitan area on a guideway network or grid of lines spaced one or two miles apart. Small vehicles would travel over the guideway network using standard routes, or possibly automatically from origin to destination. In this system, the vehicle could convert easily from travel on a street under driver control to travel on the automated network.
  - Fast transit link systems to provide rapid access throughout a metropolitan area between a number of distant points. These systems would move relatively high volumes of people between central cities and suburban growth centers, and between satellite centers and airports. Vehicles would travel faster than 100 mph, carry 20 or more passengers, be automatically controlled, and be capable of operating either independently or coupled into trains.

The UMTA's national urban transportation R&D activity also seeks to understand the social, economic, and institutional barriers that constrain the application of transportation technology to improve the quality of urban life. The participation of State and local governments, public agencies, private industry, labor and trade associations, and individuals is being solicited. (Airport access is only one of the many problems included in urban planning, and it often has a low priority.

A major near-term R&D effort for surface transportation concentrates on improving bus services, including better management, more efficient operations, new techniques for routing and scheduling, new vehicle designs, and new propulsion systems. Objectives are to use manpower and equipment more efficiently, to improve the quality and coverage of service, and to make the vehicles less obtrusive and less polluting.

Increasing quality and service levels will greatly increase the probability that bus service will play an important role in complementary airport ground transportation. Advances such as automatic fare collection, computerized techniques for vehicle location, schedule adherence and routing, traffic control systems giving buses priority traffic clearance and routing, demand-responsive bus-routing traffic systems, comfortable bus interiors, and new propulsion systems will attract more users.

The major problem, however, in the labor-intensive bus transportation industry is financial. Bus systems must be considered from a total community and, perhaps, Federal, State, and local viewpoint, because level of earnings is directly related to level of tax revenues collected. This should lead to adequate community (or broader) financial support.

The air traveler may also benefit from future progress in urban rail transportation. Improvements may be expected in rail equipment use and safety, in the use of existing urban railroad trackage by a dual-mode railbus, in use of underground tunnels with improved environmental control, in ride quality, and in propulsion.

A number of projects are currently under way to advance surface transportation, ranging from actual construction to exploration of new concepts. At the Dallas-Fort Worth regional airport, a collection and distribution project will permit UMTA to use the new airport as a site for demonstrating a prototype transportation system for possible use in a wide number of urban applications. The plan includes construction and testing of a vehicle, guideway, and control system. This will be closely coordinated with public transportation systems of Dallas and Fort Worth.

The San Francisco Bay Area Rapid Transit system is well under way. Inauguration of service is expected in mid-1972. Initially, this system will not serve San Francisco International Airport. Later extensions will serve both the International and the Oakland Airports.

A demonstration of tracked air-cushion vehicles is planned between Los Angeles International Airport and the San Fernando Valley, with one station west of Beverly Hills. The Department of Transportation, through UMTA, has provided an engineering and feasibility grant. The 150-mph speed permitted by existing tracked air-cushion vehicle technology is adequate for the 16-mile airport access run.

A feasibility study has been made for a high-speed access system to a proposed new jetport in southern Florida. Vertical and short takeoff and landing airborne vehicles, in addition to high-speed rail, monorail system, and tracked air-cushion ground vehicles, were examined as candidate systems.

OFF-AIRPORT FACILITIES

Off-airport passenger and cargo satellite consolidation and distribution systems would reduce the main source of ground congestion at the airport – roadway traffic. Passengers and cargo would make use of the airport for enplaning and deplaning only. All ticketing, booking, and consolidation processes could be accomplished at

TABLE 4.5. POSSIBLE HIGH–SPEED GROUND TRANSPORTATION ALTERNATIVES

CLASS			CHARACTERISTICS	SPEED RANGE, mph	GUIDEWAY
STATION-TO-STATION	TRACKED AIR–CUSHION SYSTEMS		Vehicle guided along track and supported by air cushions	150–300	Flat concrete horizontal surface for support and vertical surface for guidance. Inverted T, box and U
STATION-TO-STATION	ROLLING–SUPPORT SYSTEMS		Vehicle guided and supported by either conventional surface rails or monorail	150–300	Conventional or improved rail roadbeds or elevated structures modified to be straighter and more level
STATION-TO-STATION	TUBE–VEHICLE SYSTEMS	Ambient Atmospheric Pressure	Vehicle guided and supported by enclosed guideway or subterranean tube	150–300	Concrete or steel tubes. Can be located above-ground, on surface or underground
STATION-TO-STATION	TUBE–VEHICLE SYSTEMS	Evacuated	Evacuated guideway reduces aero drag. More expensive to construct, but potentially more economical to operate	200–400	Same as above, and pumping systems and airlocks also required
STATION-TO-STATION	TUBE–VEHICLE SYSTEMS	Electro-magnetic Suspension	Vehicle guided and supported electromagnetically in tube	200–500	Passive aluminum loops or structure buried in guideway
DOOR-TO-DOOR	MULTIMODAL SYSTEMS		Vehicle uses both conventional surface routes and new automated guideways for intercity portion of trip. Optimum configuration depends on urban system interface: bimodal or ferry pallet	80–150	Suspended and over-running
DOOR-TO-DOOR	AUTO-TRAIN SYSTEMS		Conventional autos, along with drivers and passengers, are loaded on a carrier vehicle and transported over the high-speed link	100–150	Standard gage for lengthwise loading and ≈ 17 ft for crosswise loading of autos
DOOR-TO-DOOR	AUTOMATED–HIGHWAY SYSTEMS		Conventional autos and highways are modified to provide automatic control of traffic flow on the high-speed link of intercity trips	Higher than present auto speeds	Conventional concrete highway, special-purpose or modified to accommodate appropriate control system
CONTINUOUS–CAPACITY SYSTEMS			Transportation is available continuously. Employs variation of endless-belt principle	15–25	Enclosed belts, elevated or subsurface

Source: Ref. 5.

satellite facilities, located at strategic points in the metropolitan and suburban areas. Each airline would disperse its staffs to decentralized facilities. Special buses and trucking services would shuttle consolidated passenger and cargo loads to and from the airport and distribute loads to and from the points of origin and destination. No other passenger or cargo vehicles would be needed at the airport. Sightseers and visitors could view aircraft operations from some convenient outside location.

Unless the airport owned the satellite system as well, some loss of revenues to the airport – from parking fees and concessions – would occur. It must be recognized that with today's system, airport congestion and passenger delays actually contribute to increased revenues.

SUSPENSION	PROPULSION	POTENTIAL ADVANTAGES	DISADVANTAGES
Air cushions pressurized by centrifugal or axial compressors	Linear electric motor with reaction rail in guideway; propeller driven by gas-turbine or rotary electric motor	Guideway may be cheaper to build and maintain; smoother ride at high speeds than rail system; no wheel hop or traction limitations	Power to support weight of vehicle is high. Air-cushion equipment may be noisy. Switching is difficult
Steel wheels on welded steel rail; rubber tires	Rotary electric motor; gas-turbine engine (both with drivethrough wheels); linear electric motor	Since wheels support vehicle, no energy is required for support. Power is required only for propulsion. Extends conventional technology to a higher speed range	Wheels start to slip at high speeds. Guideway maintenance cost may be high. Monorail poses switching problems
Wheels, rails or air cushions	Electricity preferable to combustion engines	Can minimize disturbance to environment or corridor community. All-weather operation. The one system offering complete aerodynamic control. More chance of straight-line paths	Tunneling costs are high at present. Existing power-pickup devices are unsuitable for high speeds. At present, tube-vehicle technology is not as advanced as that of some other classes. Evacuated system poses special safety and maintenance problems
Primary wheels on rails	Linear electric motor. Pneumatics and gravity-assisted acceleration and braking	High speeds because of reduced aero drag, in addition to above advantages	
Electromagnetic forces generated by superconducting magnets on vehicle	Same as above	Presently the only suspension candidate for systems running in evacuated tubes at speeds unsafe for metallic wheels	Intense magnetic fields may affect passengers and subsystems. Vehicles may require heavy shielding
Steel wheels; or rubber tires; magnetic; air cushions	Linear electric motor, rotary electric motor; internal-combustion engine	May offer shorter door-to-door travel time. Retains advantages both of private auto and high-speed mass transit. Possibly compatible with urban systems	Vehicle unit costs/passenger are higher than for conventional auto or mass transit; maintenance of privately owned vehicles may require verification before use on public guideway
Steel wheels on welded steel rail	Rotary electric motor; gas-turbine engine; diesel-electric locomotive	Offers door-to-door service. No parking problem at terminal	Flexibility of loading for different destinations is poor for lengthwise loading
Auto wheels with conventional suspension	Internal – or external – combustion engine or electric motor	Offers increased safety and density over existing highways. Driver becomes backup controller. Door-to-door service. No terminal interface required	Vehicle maintenance may be beyond control of system operator and therefore inadequate; merging for entry, exit and lane changing requires complex central control system
Rollers; wheels; air	Rotary and linear electric motors; air pressure	Offers uninterrupted, continuously available service to many passengers	Passenger acceptance is not wide spread. Slow. Not suited for growth or intercity speeds

RESEARCH AND DEVELOPMENT REQUIREMENTS

R&D for an effective passenger collection and distribution system, including both complementary surface transportation and its interfaces with air transportation, should be aimed at the following objectives:

- A geographic area generating air travel demand should be covered by a system of collection and distribution points with a density depending on expected patronage. The distance between a collection and distribution point and the passenger's origin or destination should be sufficiently small to encourage the use of a public system instead of a private automobile.

- The frequency of service and the length of transit time should make the surface portion of the trip a reasonably small fraction of the door-to-door trip time.
- Travelers should be able to check their baggage close to their point of origin and recover it close to their final destination. They should not be required to carry baggage over long distances. Baggage-carrying assistance should be available to the aged, the infirm, and the encumbered. Travelers with baggage should not be mixed with rush-hour commuters.
- Modal interchanges should be convenient and fast, and require minimum walking.
- The system should have flexibility to adapt to traffic growth, to new airports in areas already served by existing airports, and to shifts in regional population patterns.
- Complementary ground transportation should have levels of comfort, safety, and security at least as high as those of air travel.
- Advanced technology should be exploited to the fullest extent permitted by economic profitability or by subsidy set by social policy.
- The system should have the ability to attract and retain patronage.

An intensification of on-going research is required to insure continued improvement of complementary surface transportation and intermodal connections associated with air transportation.

High total costs, and thus resultant high rates or requirements for subsidy, are probably the major impediments to improvement. It is recommended that research be oriented toward lowering costs, and that the cost-reduction potential of research projects be an important consideration.

There is the need to experiment with different systems at several airports to establish public acceptance, patronage, reliability, and realistic costs. Links of 15 to 50 miles would offer a chance to find the best solutions by actual operating experience. In these demonstrations, special attention should be given to the interface between the access link and the intra-airport people and cargo movers.

POLICY CONSIDERATIONS

In 1970, the Congress expanded the Urban Mass Transportation Act of 1964 to provide for a "coordinated urban transportation system as part of a comprehensively planned development of the urban area." The Act (ref. 6) now provides a mechanism for disbursing at least $10 billion between 1970 to 1981 in partnership with local communities. Included, but as a limited portion, is recognition of the airport access problem. The Act also explicitly calls for cooperation among Federal agencies and authorizes the Secretary of Transportation to take overall Federal responsibility.

The UMTA has been the DOT focal point for encouraging, evaluating, and assisting local communities applying for financial assistance in terms of actual projects, technical studies, or R&D grants. Local communities can also receive aid on a 90%:10% ratio from the Federal Highway Administration, and can obtain funds in selected cases from the Federal Railroad Administration on a 67%:33% cost-sharing basis.

The local community, and not the Federal Government, has the final say about where emphasis is to be placed in its urban transportation system. Airport access and complementary surface transportation are considered by most communities to be a subordinate part of their overall transport problem. Urban pressures to solve transportation problems that plague the nonair commuter often have higher priority and preempt funds.

Congress, in the Federal-Aid Highway Act of 1970 (ref. 7), provided that in approving Federal

highway projects, the Secretary of Transportation shall give consideration to projects that will provide adequate, direct, and convenient public access to passenger and cargo terminal buildings and public airports or seaports.

The present airport access problem, with its large dependence on intermodal connections, raises questions of philosophy as well as practice. It would seem fruitless to develop a national system of airways and airports geared toward the year 2000 if intermodal adjuncts are retained at the operational and design levels of 1960. Traditionally, airport access is the responsibility of the local community. This inhibits any nationwide systems approach to solving airport access/egress problems.

Local officials have attacked airport-access problems with varying degrees of success. They are swamped with other pressing problems that have left them with scant planning lead time and limited funds to meet their responsibilities towards the air transport system. As a result, the record on improvement of airport access has not been remarkable.

The Federal Government must not preempt the role of the local community in the matter of airport access, but there is a pressing need for closer cooperation with local planners. This should be in the form of technical assistance, selected demonstration programs, and criteria for airport grants-in-aid that more fully recognize the importance of door-to-door trip or shipment concepts.

FAA advisory services and development standards should consider the total airport situation. Communities applying for financial aid should be required to demonstrate that proposed airport access and intermodal adjuncts can handle normal peak capacity effectively for a long time in the future.

The Secretary of Transportation should assure that there is a formal plan for airport-access intermodal interface associated with grants in financial aid dispensed by all the DOT modal administrations. National air transportation "systems planning" advisory services should be developed jointly by DOT agencies and should provide guidance to metropolitan planners.

The Federal Government should also recommend intermodal performance standards and evaluate their application jointly with the local community. Examples might be standards for the longest allowable walking distance from a baggage-claim area to a taxi-loading stand or for the maximum allowable time from baggage claim to the departure of downtown transportation. Compliance with such standards could be a prerequisite for Federal funds.

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5. SPECIAL CONSIDERATIONS

Special Considerations

ENVIRONMENTAL FACTORS

It is evident that the application of new technology to serve man's needs must first be approved by a public that has become greatly concerned with the quality of its environment. The public is unwilling to tolerate applications of technology that degrade the quality of the environment, even in technical areas that have become a part of our daily lives, and is expressing a very strong intent to prohibit new encroachments.

The developer and sponsor of technological systems must approach this new situation from the outset knowing that compatibility with the environment must be achieved and that the public must be informed of the plans and the ultimate nature of the technology. This public service by the sponsor should not stem from a reaction to existing national or local legislation but should be a result of true concern over any adverse impact new technology might have on the quality of the environment. The developer and the sponsor of any new technological application today must convince both users and nonusers of its importance to the community and its compatibility with the public's expectations regarding the quality of the environment.

Public concern about the environment can be divided into six elements: (1) noise; (2) air pollution; (3) water pollution; (4) esthetics; (5) ecological disturbances; and (6) meteorological changes. These elements must be studied and adequately handled in planning and informational activities. They represent constraints which the developer must carefully consider in assessing the adequacy of the technology base and the economic trade-off.

The problem here is that absolute requirements do not exist and may never be fully quantified because of the difficulty of defining the "quality of the environment." A flexible approach in planning and implementation of new systems must therefore be taken at the outset to realistically appraise environmental requirements and provide compatible system characteristics. In addition, resources must be allocated to permit developing factual information and providing it to the public, and there must be a capability to react sympathetically to environmental concerns. From a historical point of view, such an allocation of resources may seem unreasonable, but when weighed against the price of delays in implementation and income lost because of delays, the importance of such an allocation is evident.

The effects of the failure of sponsors to anticipate public reactions can be seen by examining some of the noise problems around large airports. The high-noise area around the J. F. Kennedy Airport in New York, for example, includes 35,000 dwellings, 22 public schools, and several dozen churches and clubs (ref. 1). This area plus the high-noise area around the Los Angeles and Chicago airports covers three times as much ground as all the land redeveloped during the 16 years of urban renewal (42,000 acres) at a cost of $5 billion. In Los Angeles, as of January 1971, there were 34 suits against the airport for damages arising from jet noise, and the Los Angeles Unified School District is seeking $95 million in aircraft noise damages.

This section of the report is devoted to a discussion of noise and air pollution. At the present time, sufficient data are not available for an accurate assessment of meteorological and climatic changes that might be due to aircraft emissions. Those effects warrant further study but will not be treated here.

AIRCRAFT NOISE

For aircraft, noise is undoubtedly the most critical of the environmental or nonuser-acceptability problems. Solutions to noise problems in some cases solve many of the other problems associated with acceptability of new technology by the nonuser community. Conversely, noise may be the trigger mechanism for public reaction against many of the other

community-acceptability problems of the air transport industry today.

Public objection to aircraft noise created a ground swell that resulted in the passage of a law (ref. 2) that, among other items, empowers the FAA to certificate new aircraft for noise. It also provides a mandate for the immediate and effective relief of airport noise by the FAA. The first rule promulgated under this authority pertains to new subsonic turbofan aircraft with engines of bypass ratio of two or more, and revised versions of existing aircraft requiring new type certificates. Specific noise levels for these aircraft are promulgated in Part 36 of the Federal Air Regulations (ref. 3) as a function of the aircraft gross weight. In general, this rule, as it applies to changes of existing turbine-powered aircraft, prescribes no absolute numbers but rather requires that such changes do not result in a higher noise level than that generated by the parent aircraft.

As mentioned in the "Commercial Passenger Service" section, the short-haul systems that can be most effective in meeting future transportation goals in high-density areas will require new vehicles, new STOL-ports and VTOLports, and new operational procedures. The acceptance of these new systems by State and local authorities, and the community, will depend on being able to demonstrate a minimum of disbenefits such as excessive noise. The short-haul systems will therefore have to fit into the community noise pattern.

Effect of Noise on the Growth of Civil Aviation

Some of the many ways in which noise has direct and indirect effects on the growth of civil aviation are discussed below.

- *Airports require more land.*
  One way to reduce the noise impact in the vicinity of an airport is to provide noise buffers by acquiring more land in the airport approach and departure areas. There are two main consequences of using land as a noise buffer. First, the additional land is a cost to the aviation system – a cost that presumably should be met by system users. Second, the noise-buffer land has an opportunity cost to the community; that is, there may be uses for the noise-buffer land that could serve the community better were it not for the aircraft noise.

- *Airport capacity is reduced.*
  Noise has reduced and will continue to reduce airport capacity in three ways. First, noise (typically, no jet operations from 11:00 p.m. to 7:00 a.m.) limits the number of hours the airport can be used. This has the additional adverse effect of adding the nighttime traffic (some of which may ideally operate at night, certain cargo, for example) to the daytime traffic, which may already have peak demand problems. Second, it is common to restrict runway usage because of noise (usage of certain runways may expose more people to noise than others). Thus, the utilization of an airport's existing or potential runways is reduced. Third, flight-path restrictions in the terminal area airspace generally make certain portions of the airspace unusable and thus further reduce airport capacity and often increase aircraft travel time and cost.

- *Existing airports are threatened.*
  At the same time that aircraft noise intensity and noise events have been increasing, many communities have been closing in around airports. The continued existence of an established airport is threatened at the very time it needs to grow. Increased operations will generate more noise and hence more pressure to reduce and even prohibit airport activity.

- *Suitable locations for new airports cannot be found.*
  - As the Nation grows and evolves new patterns of distribution of population and industry, new airports will be needed if aviation is to offer a

viable alternative in a balanced transportation system. Even with increased airport size to accommodate noise buffers, community reaction to potential airport noise is such that suitable new locations are difficult to find.

- The effects of aircraft noise are not confined to the most immediate airport neighbors, they also cause appreciable reaction in more distant communities along flight paths. Large numbers of citizens can see themselves as potential airport neighbors or potential residents under heavily used flight routes. Unless the noise problem can be resolved, sites will be selected that are not best suited to supporting the air mode in a balanced transportation system, with such adverse side effects as increasing user travel time and cost of getting to and from airports.

- *Aviation growth is impeded.*

Although aircraft noise at airports has a much stronger impact on short-haul aviation, the handicap to long-haul is also appreciable. For example, if the effect of noise were to cause an airport to be located 10 miles further from the populated area it serves, the additional cost to travelers and employees could exceed $30 million annually for each major airport.

Goals of Noise Reduction Efforts

Noise is measured by a variety of techniques, each yielding different indicators of noise severity. One of these, Perceived Noise Level, is a measure of the subject annoyance of a sound and is expressed in units of PNdB (perceived noise in decibels). Figure 5.1 presents typical noise levels for a number of sources in terms of PNdB.

The value of Perceived Noise Level adjusted for the presence of discrete frequencies as well as for the time history has been adopted by the FAA as the official measurement standard and has been designated Effective Perceived Noise Level, expressed in units of EPNdB. Consideration in the study of the problem of public acceptance of new systems has led to the recommendation of a long-term research goal of 80 EPNdB at the airport boundaries for STOL and VTOL vehicles that must operate in areas of high population density. It is believed necessary to establish goals at these difficult-to-achieve levels to properly

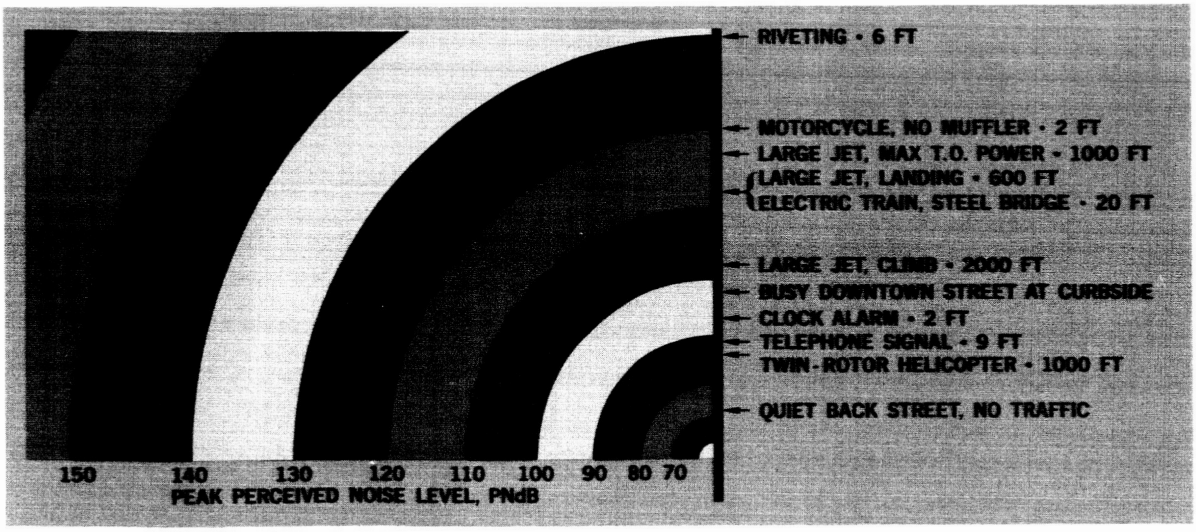

Figure 5.1. Typical noise levels.

stimulate and orient R&D activities so that the objective of gaining public acceptance of new air systems can be achieved at the earliest possible time.

The ultimate goal of the noise-reduction activity should be to reduce the noise of civil aviation systems to a level acceptable to the community. Specifically, these goals may be expressed as follows:

- Reduce the noise of the air transport system sufficiently to provide an acceptable noise environment at existing facilities.
- Reduce the noise of future air transport systems so that this factor will not constrain their growth.
- Develop a technology base such that future aircraft systems can be designed and introduced into commercial use with minimum noise impact.

Magnitude of the Noise Impact

The importance of aircraft noise-reduction programs can be shown by estimates of the cost of various alternatives for making noise tolerable. Although data are not available for firm conclusions on each of the available alternatives, it is at least clear that the cost of noise will involve billions of dollars. Thus, R&D programs to guide the selection of alternatives can be expected to produce large payoffs.

The following items illustrate the magnitude of potential noise costs.

- *Cost of land.*
  The area of land encompassed by the 110 PNdB takeoff contour of a long-haul four-engine civil jet is approximately 600 acres; the additional area of land encompassed by the 100 PNdB contour is approximately 7,000 acres. Assuming that a typical airport has eight runway ends, a 10-PNdB noise reduction would "relieve" about 50,000 acres. To buy this acreage, assuming a new airport were being established, say, 30 miles from a major city, would cost some $350 million at an assumed cost for undeveloped acreage of $7,000 per acre. Assuming that three new airports were involved, the savings would equal the billion dollars estimated as the cost to quiet the current civil aviation jet fleet. To achieve the same noise exposure reduction around existing airports (where land costs are much higher, as may be seen from Figure 7.6 in the "Benefits" section), the land purchase costs would be many billions.

  An intercity STOL system will be viable only if STOLports are located relatively close to population centers. Although STOL runways are shorter and flight paths steeper, the cost of land can be as much as $500,000 per acre. Thus, the cost of noise-buffer land to reduce noise by 10 PNdB at STOLports will be comparable with the cost at large CTOLports that are distant from populated areas.
- *Aircraft operating delays.*
  Many airports are experiencing delays in aircraft operations because of noise-caused restrictions on the use of runways and airspace. It is conceivable that noise restrictions could reduce the capacity of an airport by 20%. Thus, an airport with an annual demand of 450,000 operations could suffer an annual aircraft-delay cost of about $1 million. Although this value is considerably lower than other costs previously discussed, it must be realized that this particular cost is encountered to some degree at all existing airports where noise-abatement procedures have been or will be implemented.

  The above estimates are based on broad general assumptions but they demonstrate that there is significant reason for Government concern. It should also be

noted that there will be costs beyond those discussed above. Some examples are the cost of a new airport required because of noise; the cost of establishing alternative travel modes where noise curtails short-haul air service; and the economic impact on an area from lack of adequate air service.

Sonic Boom

Sonic booms were infrequent in the early days of experimental and military supersonic flights and were considered a minor nuisance compared to the airport noise problem. Since the early 1960's, growing interest in a commercial SST and the realization that many people might be exposed to sonic booms many times a day has aroused concern over the effects and acceptability of sonic booms over communities. This concern has reached the point where it could severely restrict or even prohibit use of supersonic transports in some areas. Since current technology cannot reduce sonic boom enough, supersonic flight over land will not be possible in the near future.

A Department of Transportation notice of proposed rulemaking to ban civil supersonic flight over land was filed on April 10, 1970, and was published in the *Federal Register* on April 16, 1970 (ref. 4). In addition to filing this proposed amendment to the Federal Aviation Regulations, the President of the United States, the Secretary of Transportation, and other representatives of the Executive Branch have said that commercial supersonic flight over land will not be permitted. Despite these assurances, some critics contend that the regulation might be changed or revoked when commercial supersonic flight becomes a reality.

To dispel these fears and to assure the American people that there would be no overland flight in this country by civil supersonic aircraft at speeds causing a sonic boom, the United States Senate, 91st Congress, adopted the language of the Department of Transportation's proposed regulation in a bill approved by the Senate on December 2, 1970 (refs. 5, 6). The bill, however, failed to come up for a vote in the House of Representatives.

The intent to prohibit sonic booms legally was based on the belief that the statute would not affect the economic viability of the U. S. civil supersonic transport. In fact, the prototype SST program has been proceeding for a number of years on the assumption that commercial supersonic flight over land would not be permitted, and most marketing and economic projections have been based on this premise.

If the effects of the sonic boom could be considerably reduced, long-haul overland flights by future generation supersonic transports would be possible, resulting in a greatly increased potential market for supersonic transport aircraft. However, the development of a high-speed (Mach 2+) transport with acceptable sonic boom characteristics would require a technological breakthrough. The benefits that would accrue from such a vehicle justify pursuing a concentrated R&D program in the fields of propulsion, aerodynamics, and structures aimed at reducing the sonic boom to an acceptable level while still permitting design of a viable commercial transport aircraft.

Reason for Government Involvement

Although it is clear that the effects of aircraft noise on civil aviation are substantial, it might not necessarily follow that the Federal Government should be deeply and intimately involved. The aircraft noise problem could be placed in the category of a local matter, which would allow the Federal Government to take only an indirect interest. However, several overriding issues appear to establish the Federal Government's direct involvement.

- *There is no suitable market mechanism to quickly and equitably correct the noise problem.*

  The nature of the free-enterprise system encourages the market mechanism to

supply the needs of the user. In special cases where the market is neither operating properly nor in the public interest, it may be appropriate for the Government to intervene to secure the desired results. In the case of aircraft noise, there appears to be no market mechanism that can respond promptly and effectively to the deleterious effects of aircraft noise on the growth of civil aviation. That is, no one is directly in the business of buying quietness.

- *Government is broadly involved in setting environmental-pollution standards.*
  Aircraft noise is but one aspect of the much more general problem of environmental pollution. Since there is considerable Federal Government concern, as well as Government programs to set standards and make regulations, an attack on aircraft noise is only part of a broader Federal policy.

- *Government certification of aircraft.*
  In its role of protecting the public, the Government certificates aircraft for airworthiness. Since certification of aircraft for noise is akin to certification for airworthiness, it is proper that this task be the responsibility of the Government.

- *Government participation in airport location and development.*
  In the past under the 1946 Federal Aid to Airports Act and in the future under the Airport and Airway Development Act, the Federal Government, recognizing its responsibility to promote a safe and efficient air transport system, has had a voice in, and has contributed funds to aid in, the selection, development, and modification of airports. The Government responsibility regarding airports has been reinforced by creation of the Department of Transportation to effectively meet the challenge of achieving a balanced transport system.

- *Government establishment of flight paths.*
  Airport runway use and the terminal area approach and departure paths are most important in determining what urban areas will be exposed to noise. All of these are established by the FAA.

Courses of Action

Aircraft noise is an extremely complex problem that is being attacked in three general ways: by decreasing it at the source; by operational changes; and by land-use compatibility.

Reduction of Noise at Source. Most aircraft propulsion systems in the commercial air fleet use the turbofan engine shown schematically in Figure 5.2. The major noise sources are: the primary exhaust stream, the fan exhaust stream, the fan and compressor forward-radiated blade noise, and the fan aft-radiated blade noise. Noise from turbine blades and other sources is radiated rearward. Other minor forms of aircraft noise (e.g., noise radiated from the turbulent flow over flaps, spoilers, and landing gear) are generally masked by the intense noise from the major sources.

The magnitude of the source noise-reduction problem can be better appreciated when it is recognized that the energy converted to noise is a small fraction of the total energy (about 1%). Devices that give appreciable reduction must radically change the mechanism through which the acoustic energy is generated, or provide absorption or attenuation of the sound after it is generated.

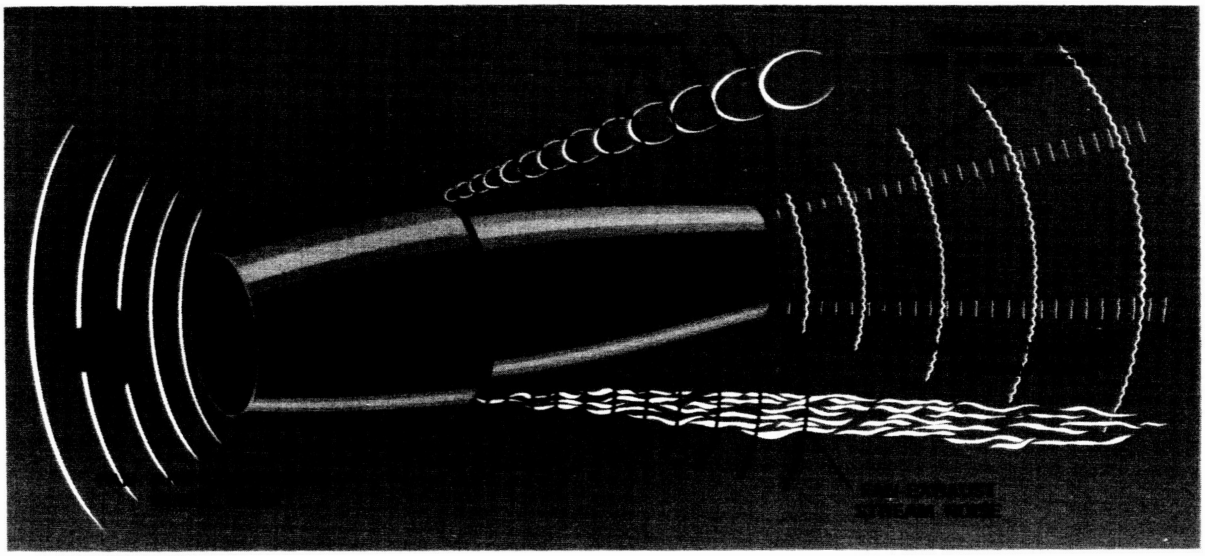

Figure 5.2. Noise-generation sources in the turbofan engine.

The noise emanating from a typical turbojet engine is shown in Figure 5.3. The dominant noise source during takeoff is the jet, whereas under approach conditions, the dominant source is the fan. The engine-inlet and fan-exit noise can be significantly reduced by insulation procedures. Recent NASA research work on inlet and fan-exhaust insulation has demonstrated as much as 15 EPNdB reduction under approach conditions. Noise reduction under takeoff conditions, where the primary jet noise predominates, is difficult to suppress, and there has been only limited success in this area so far.

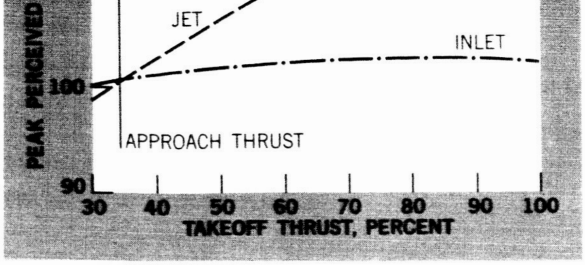

Figure 5.3. Peak perceived noise level in a B727–200 flyover. *Source: Ref.* 7.

A recent study of acoustic treatment of existing commercial aircraft shows retrofit costs to be between $200,000 and $1 million per aircraft. In addition to this initial conversion cost, other factors may increase the operating costs (ref. 8). It is evident that controlling noise at the source is very costly. Additional studies are necessary to determine if these costs are justified and if this is a cost-effective approach to the solution of the aircraft-noise problem for current aircraft.

Although the NASA Quiet Engine Program has shown some very successful results and plans are being made to extend this activity (ref. 9), it appears that further intensive research in this area may yield significant gains. A program is needed to investigate basic noise-generating mechanisms. This should lead to a better understanding of the phenomena and should indicate other potential solutions for noise reduction at the source. This technology could then be incorporated in future

engine designs where noise must be treated as one of the primary design variables, at least on a par with the traditional parameters of thrust/weight ratio and specific fuel consumption. Such research and development activities may require 5 to 10 years to reach fruition. Experience in other fields has shown that a combination of stringent goals and high levels of activity in applied research tends to produce results far beyond what can normally be projected on the basis of the current state of the art. The need to find better solutions to the noise-generation problem at the source cannot be challenged. Approaches that minimize the penalties on performance and provide for lower cost in implementation are essential ingredients for rapid and continuing progress in this area.

Path Control. The noise level at any point on the ground is a function of the throttle setting, the aircraft flight path, and atmospheric effects. Aircraft operational procedures are closely controlled by Federal regulation, and changes in operating procedures to reduce noise must be carefully planned and tested to ensure that there is no degradation in safety. The mechanisms for accomplishing the noise-abatement operating procedures are based on the concept of ensuring maximum separation between the noise source and the receiver or reducing operating power while overflying noise-sensitive areas (or both). Takeoff procedures have been explored in considerable depth in the past, and various noise-reduction power-cutback techniques have been applied in practice. Approach procedures have also been investigated; it is in this area that considerable potential for improvement appears to exist. Figure 5.4 shows representative approach profiles (aircraft altitude as a function of distance from airport threshold). Current procedures generally consist of an approach at about 1,500-feet altitude with an intercept of a 2.75° glide slope at about 5 miles, which is followed until touchdown. The figure indicates that alternate intercept altitudes as well as variable-glide approach angles may be utilized for noise-abatement approaches (ref. 10).

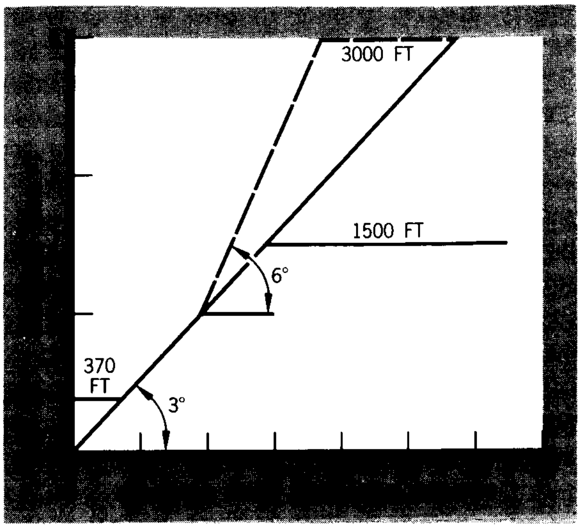

Figure 5.4. Noise-abatement operational procedures approach profiles. *Source: Ref. 10.*

The combination of the 3,000-foot intercept altitude and the two-segment (6°/3°) approach path might permit a noise reduction on the order of 10 dB over appreciable distances. These approaches, shown schematically, are overly simplified for clarity. Even further gains might be realized by a variable-angle approach that in turn could be integrated with effective programming of approach configuration and approach power.

The higher approach path and rapid climb characteristic of STOL aircraft will be beneficial with respect to noise. It has been estimated that the area affected by a given level of noise exposure for a STOLport may be only about 5% as large as for a conventional jetport. It should be remembered, however, that the low cruise altitude for STOL aircraft on short-route segments, perhaps under 50 miles, must not be permitted to introduce new noise problems.

Noise Receiver. Aircraft noise signatures involve different, very complex spectral, temporal, and special functions of the sound pressure. It is difficult to develop a single noise evaluator for all types of aircraft. The development of effective perceived noise level in the units of EPNdB appears to have great potential, but continued

TABLE 5.1. SIGNIFICANT AIRCRAFT–NOISE–RELATED EVENTS

DATE	EVENT
1952	AIR FORCE AIR BASE NOISE STUDIES
1956	JET EXHAUST NOISE SUPPRESSOR DEVELOPED
1957	PERCEIVED NOISE LEVEL CONCEPT INTRODUCED
1958	PORT OF NEW YORK AUTHORITY 112 PNdB LIMIT; 707 SERVICE
1960	LONDON AIRPORT 110 PNdB DAY AND 102 PNdB NIGHT LIMITS ESTABLISHED
1961	TURBOFAN ENGINE INTRODUCED
1962	GRIGGS DECISION
1963	U.K. PARLIAMENTARY INVESTIGATION;
1964	U.S. SST DESIGN COMPETITION
	HEMPSTEAD AND PARK RIDGE ORDINANCES;
	MARTIN vs PORT OF SEATTLE: AIRCRAFT NOISE COMPENSABLE
1965	OFFICE OF SCIENCE AND TECHNOLOGY JET NOISE STUDY
1966	PRESIDENT'S TASK FORCE; REGULATORY INTENT; LONDON MEETING
1967	DOT INTERAGENCY AIRCRAFT NOISE ABATEMENT PROGRAM; TRIPARTITE MEETINGS
1968	PUBLIC LAW 90-411
1969	FAA NOISE RULE; ICAO SPECIAL MEETING

Source: Refs. 2, 3, 7, 9, 10.

development is necessary to improve the ability to more accurately assess the psychoacoustic impact. Many attempts have been made to develop number rating systems for cumulative aircraft noise exposures related to community acceptance. The Noise Exposure Forecast is a methodology currently used to predict such single number ratings of the noise. The factors involved include the absolute noise level, noise spectrum, maximum tone, noise duration, aircraft type, mix of aircraft, number of operations, runway utilization, flight path, operating procedures, and time of day. The Noise Exposure Forecast contours about a given airport may be computed using the mathematical procedures involved. By relating contours of different magnitudes to receiver assessment of noise impact, it may be possible to control the residual aircraft noise through selected use of the airport adjacent land areas. The most effective utilization, however, of noise exposure forecasting in land use planning techniques is realized at new airports under development.

Additional areas of action for land use include soundproofing buildings, purchasing noise buffer zones, locating airports on the peripheries of cities, operating only V/STOL aircraft in noise-sensitive areas, and building airport-compatible cities.

Government Policy

Before examining the Government's policy with respect to aircraft noise abatement, it is desirable to review the historical events leading to the present position. Table 5.1 outlines some of the significant events in the chronology of the modern day aircraft noise problem.

In 1952 the Air Force initiated some of the early R&D activities directed at aircraft noise reduction. The introduction of the 707 and DC-8 aircraft to commercial service in 1958 and 1959 clearly pointed out the need for more effective jet noise suppressors.

Some of the suppression devices developed then are still used today. Possibly the first U. S. airport proprietor to establish noise standards was the Port of New York Authority in 1958. Using the then evolving concept of perceived noise level, the Port Authority established 112 PNdB as a monitored limit for the protection of the airport neighbors. London-Heathrow Airport followed suit with the establishment of 110 PNdB for daytime and 102 PNdB for nighttime operations.

The first major improvement in the aircraft noise situation followed the introduction of the turbofan engines, which extract energy from the jet exhaust to drive the bypass fan. The bypass flow also mixes with the primary engine flow, thereby achieving lower jet velocity and hence lower jet noise.

While the technological advances were taking place, significant legal action was under way and in 1962 a major decision was reached in the "Griggs versus Allegheny" case. In that case it was determined that the land of the airport neighbors

was being taken by airport operations. It was decided that the legal responsibility for that "land taking" lay with the airport operators, in that they had original control of laying out the airport and developing flight patterns.

The Oren Harris Congressional hearings in 1959-62 represented the first Congressional recognition of the seriousness of the aircraft noise problem. Congressional attention to noise has increased significantly since then. Hempstead, N. Y., and Park Ridge, Ill., passed ordinances aimed at the Port of New York Authority and Chicago's O'Hare Airport, respectively, to restrict aircraft operations thereby reducing noise. These restrictions were not allowed by the courts, and subsequent attempts to impose curfews on airport operations have been denied on the grounds of constraint of interstate commerce.

In 1965 the Government's position was further defined when the President established a study group in the President's Office of Science and Technology. This group coordinated the activities of the Government agencies involved until 1967, when the interagency aircraft noise-abatement program was transferred from the President's Office of Science and Technology to the Department of Transportation. Now all Governmental bodies involved in the problem of aircraft noise are participants in this program, currently directed by the Department of Transportation's Office of Noise Abatement.

In 1968, the FAA received Congressional authority under Public Law 90-411, to establish standards for relief from present and future aircraft noise. In November 1969 the FAA issued the Part 36 noise rule, which was responsive to the Public Law in that it attempted to ensure in new generation aircraft the maximum noise reduction that technology would permit, within the constraints of economic reasonableness. This rule has been adopted in concept as the basis for the International Civil Aviation Organization proposed noise rule.

Current Policy. The current Government policy is to ensure that maximum noise-reduction techniques, consistent with the technological state of the art and reasonable economic constraints, are incorporated in future aircraft designs. The Government's role is of necessity an aggressive one of pushing a continuing reduction of permissible noise levels on a continuing time scale. The Government therefore finds itself in the position of requiring technological progress in an area where technological progress has not occurred spontaneously. This policy leads not only to the establishment of acoustic standards, but also to the role of promoting the acoustic research necessary to assure that the noise standards are established on a valid scientific basis.

Recommended Policy. To meet the objective for acceptance of new air systems by the community and local governments, and to avoid further constraints in the operation of existing systems in an area of increasing concern for the environment and the "quality of life," the Federal Government policy with regard to aircraft noise should be to:

- Establish long-term research goals to reach operating noise levels that will be compatible with community and local environmental objectives. (These research goals need not be based on what is considered to be economically and technically feasible.)
- Establish regulatory standards, on a specific timetable, to attain operating noise levels that will be compatible with community and local government objectives.
- Provide funding and direction for basic research, applied research, and advanced development activities, including the necessary facilities, directed at noise reduction at the source, by operational changes and by land use modifications and planning.

Cost Considerations

Cost to Airport Neighbors. The cost of noise to the airport neighbors may be described as an "external" cost, since it is a cost imposed by the generator of the noise and for which payment is usually not provided to the airport neighbor. In some cases, the purchase of air easements represents an attempt to internalize the cost of airport noise, but the effectiveness of this technique is minimal. Some attempts have been made recently to evaluate the cost of noise in terms of the annual relative depreciation of houses within certain noise exposure areas. Although this depreciation is not an actual cost to the owner, it could be interpreted as an amount he would have to spend to obtain a similar house in a quieter area. Other evaluations of the cost of noise to the airport neighbor may be developed in terms of the cost of housing insulation necessary to realize a significant noise reduction. A very rough estimate of this cost would be about 10% of the initial house cost for a noise reduction or transmission loss through the house walls of about 15 dB. It is too early to judge the effectiveness of awards in legal damage suits as measures of the cost of airport noise because of the small number of awards to date and the large number of cases still under litigation.

Development of Effectiveness Parameters. The cost/benefit ratios of noise reduction cannot be quantitatively determined until appropriate benefit parameters are developed. In the development of these parameters, it is clear that the cost of obtaining a given decibel reduction on an aircraft will first have to be quantified. Second, this cost will have to be integrated into a total cost for the number of aircraft so reduced in noise-generating potential. Next, it will be necessary to evaluate what this given noise reduction will mean in terms of reduced noise exposure. It then becomes necessary to evaluate the monetary and social improvement realized by the airport neighbors exposed to the noise. This last quantity is particularly intangible as it may vary with many social factors of the exposed population.

The Role of Government

The development of new technology aircraft has led to correspondingly quieter aircraft, but incentives are needed to encourage the replacement or retrofitting of the current noisier aircraft in the commercial fleet. The cost impact of a large replacement/retrofit program at the present time would impose a large financial burden on an air transport industry that is currently experiencing financial difficulties. Several forms of Government support (e.g., low-interest, long-term loans; tax benefits for the replacement of noisier aircraft with quieter aircraft; and even direct subsidy) have been proposed. Leadership in such a program seems clearly a Government role.

Regulatory actions for aircraft noise abatement are governed by Public Law 90-411, which provides for applying "the results of research, development, testing, and evaluation" and considering "whether any proposed regulation is economically reasonable, technologically practicable and appropriate." It is important that these guidelines be projected into the future so that commercial operators and manufacturers can plan appropriately in the design of future systems. It is recognized that accomplishing this on a realistic basis will be a difficult task, one that will require maximum cooperation on the part of industry and Government, and coordination with international aeronautical authorities, such as ICAO. However, failure to act now to establish future regulatory goals on a time-phased basis would compound the current problem in a way that might severely limit the growth of commercial aviation.

Research goals should be established on the basis of the desired end result, that is, the achievement of noise levels that will permit the introduction of new systems which will be compatible with *future* environmental goals. This will require the acceptance of these systems by local communities so that the appropriate airports can be located, and suitable operations conducted at locations that will satisfy the transportation needs in an optimum way.

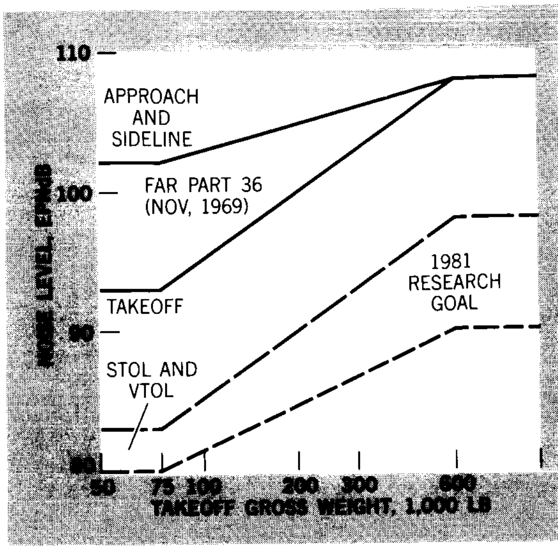

Figure 5.5. Aircraft noise levels.

At this time it appears that meeting the above criteria will require a combination of improved vehicle capability, more flexible operational procedures, and more effective land-use planning. The objective should be aircraft operations in which the *observed noise levels, at or beyond the airport boundaries, are compatible with the noise pattern of the community.* The bottom line on Figure 5.5 is the recommended maximum perceived noise level of the aircraft at the airport boundaries when operating in accordance with optimum approach and climb-out procedures; that is, 80 EPNdB for smaller aircraft, including VTOL and STOL vehicles, operating out of areas close to major activity centers, and 90 EPNdB for larger aircraft operating out of more remote jetports. As indicated, the measuring points should be at the airport boundaries. Other monitoring points beyond the boundaries should be used to make sure that the background levels are not being exceeded. In the planning of future airports, where land or land easements may be acquired at reasonable cost, it may be possible to establish airport boundaries for noise control several miles beyond the traditional runway and terminal area boundaries.

It is recognized that establishment of such ambitious research goals at this time is a controversial issue but the failure to establish a low-level noise goal now could result in the application of scarce resources to R&D activities that may fail to provide the desired solution to the noise problem on a long-term basis.

The target time period for achievement of the proposed research goal is dependent upon the resources made available, the effectiveness of the management of the R&D programs, and the actual rate of technological progress. A consensus of several experts in the field has indicated that, with appropriate funding, it should be possible to achieve a reduction of about 10 dB from the current state of the art in a 10-year period. The dashed line on Figure 5.5 illustrates this objective. As additional environmental data become available, it is expected that a more definitive evaluation of the noise-level requirements for compatibility and acceptance of new systems will be possible. For this reason, it is proposed that the area between these two lines be considered as the broad-band objective for a 10-year research effort, that is, the "1981 research goal."

Proposed regulatory standards should also be established, at least at 5-year intervals. It is important that the industry know now what is to be expected in 1976 and 1981 if it is to proceed with confidence with new system designs. Qualitative evaluations of those standards must be projected into the future to determine the cost/benefit relationships and the probable impact on the industry.

R&D Requirements for Noise Reduction

R&D requirements may be grouped in the following categories:

- The need to improve the fundamental understanding of noise generation, propagation, and attenuation.
- The evaluation of the psychoacoustic impact of noise, particularly for V/STOL and other new vehicle concepts.
- The development of new concepts of vehicle and propulsion systems with minimum noise a basic design parameter.

- Research on the generation, propagation, and alleviation of the sonic boom.
- The conduct of environmental systems demonstrations.
- The need for additional acoustic research and development facilities.
- The need to develop instrument landing systems suitable for curved approaches, steep descent, and other operational techniques to minimize noise impact.
- The need to develop personnel suitably trained to solve complex acoustic problems and able to participate in new vehicle and propulsion-system design and development.
- The improvement and implementation of land-use planning techniques, operational procedures, and other means of minimizing the impact on the environment.
- The development of analytical methods for the evaluation of cost, social impact, and technical factors to permit optimization of the approach to the solution of the overall noise problem.

Aircraft noise is the largest single impediment to the orderly growth of air commerce, and should be minimized by a vigorous industry/Government noise-reduction program. This program should seek to achieve noise levels for the existing fleet that are compatible with the communities around airports, and should seek to ensure that new forms of air commerce, such as STOL, VTOL, and supersonic transport systems, can be introduced in an acoustically compatible manner while still retaining most of their economic potential.

AIR POLLUTION

Nationwide Air Pollution Inventory

Air pollution caused by aircraft, especially the particulate emissions visible as smoke, has become a matter of national concern. In response to this concern, an initial retrofit program to cut down on particulate emissions has been put into motion by the country's airlines. (Despite the concern with air pollution caused by aircraft, it is notable that national emission inventories attribute to aircraft only 1/10 of 1% of the total particulate emissions from all sources to aircraft (ref. 11).)

Table 5.2 shows the inventory of air pollutants on a nationwide basis. This is the "normal" presentation, which includes only aircraft emissions below 3,000 feet. It is assumed that the inversion layer at 3,000 feet traps emissions in the air below. Emissions above this level are assumed to be dispersed and restructured by thermal and chemical processes. The effect of including the emissions above 3,000 feet will be subsequently illustrated.

Although it provides useful statistical data, Table 5.2 does not allow comparison of the transport modes on the basis of equal productivity. Figure 5.6 permits this comparison by showing the emissions of automobiles (complying with 1972 and 1975 emission standards, respectively), STOL aircraft, and rapid rail for a hypothetical case of 22.5 billion passenger-miles per year (slightly less than present intercity bus productivity) on an average trip distance of 100 miles.

The total air pollutants emitted by automobiles complying with the 1972 emission standards would be reduced by a factor of seven if intercity passenger travel were transferred from automobiles to STOL airplanes with current, state of the art, high bypass ratio turbofan engines. On the other hand, this pollution would be further reduced by a factor of four if the same ridership were transferred to electrified rapid-rail systems drawing power from stationary power-generating stations.

Pollution at Airports

Although the emissions from aircraft represent a small percentage of total emissions on a national basis, there has been some speculation as to whether pollutant concentrations near airports are possibly higher than national inventories

TABLE 5.2. 1968 ESTIMATED NATIONWIDE EMISSION (MILLIONS OF TONS PER YEAR)

SOURCE	CARBON MONOXIDE	PARTICULATES	NITROGEN OXIDES	HYDROCARBONS	SULFUR OXIDES
TRANSPORTATION	63.8	1.2	8.1	16.6	0.8
MOTOR VEHICLES	(59.2)	(0.8)	(7.2)	(15.6)	(0.3)
AIRCRAFT[a]	(2.4)	(n)[b]	(n)	(0.3)	(n)
OTHERS	(2.2)	(0.4)	(0.9)	(0.7)	(0.5)
FUEL COMBUSTION IN STATIONARY SOURCES	1.9	8.9	10.0	0.7	24.4
INDUSTRIAL PROCESSES	9.7	7.5	0.2	4.6	7.3
SOLID WASTE DISPOSAL	7.8	1.1	0.6	1.6	0.1
MISCELLANEOUS	16.9	9.6	1.7	8.5	0.6
TOTAL	100.1	28.3	20.6	32.0	33.2

[a]*Only aircraft emissions below 3,000 feet are included.* [b]*(n) = negligible*

Source: Ref. 11.

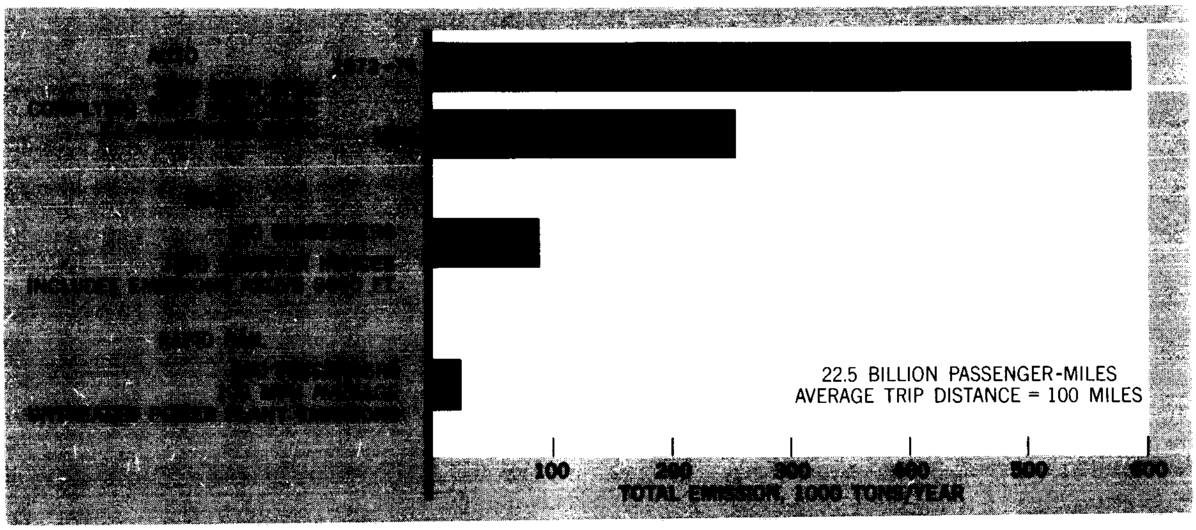

Figure 5.6. Air pollution trade-off – intercity travel modes.

would indicate, in view of the proximity to frequent aircraft operations. To assess this possibility, a study was made of the pollution concentrations in the New York metropolitan area and at the three major New York air facilities. Table 5.3 indicates that at each of the airports, the quantities of certain types of pollutants are greater than the average for the New York metropolitan area; however, overall pollution at each airport is less than the overall area average. Although this is true for the New York area, it is possible that in many regions of the country, the airport has the highest concentration of pollutants. If so, the emissions from automobile traffic associated with and concentrated near the airport are a factor.

Aircraft Versus the Auto

To further compare the relative emissions between air and auto, Figure 5.7 shows the emissions associated with the various stages of a trip from the central business district in Washington, D. C., to the central business district in Chicago,

TABLE 5.3. ESTIMATED POLLUTANTS – NEW YORK METROPOLITAN AREA AND AT NEW YORK AREA AIRPORTS (TONS/SQUARE MILE/DAY)

AREA	CARBON MONOXIDE	NITROGEN OXIDES	HYDRO-CARBONS	ALDEHYDES	PARTICULATES
KENNEDY	0.6	0.3	0.7	0.7	0.2
LA GUARDIA	1.5	0.9	0.9	0.1	0.4
NEWARK	0.4	0.3	0.3	0.03	0.1
AVERAGE	0.8	0.5	0.3	0.06	0.2
AVERAGE FOR NEW YORK METRO. AREA	4.2	0.6	1.1	0.02	0.2

Source: Ref. 12.

Illinois, by 70 passengers. The passengers go from Washington, D. C., to Washington National Airport by car, from National to O'Hare International Airport in Chicago by air, and from O'Hare to Chicago's central business district by car. The air pollutants assigned to automobile transits to and from the business district and the airport assume some doubling up (60 vehicle trips for 70 passengers) but do not assume vehicle round trips. Total emissions for each discrete trip segment (including the flight segment above 3,000 feet) are presented at the top of the figure. It should be noted that the emission indices used for the auto in Figure 5.7 are based on 1972-1974 National Air Pollution Control Administration new-car standards.

The lower left-hand portion of the figure shows the percentage of the total emission as a function of the percent of the total trip distance. If aircraft emissions above 3,000-feet altitude (assumed to be dissipated in the upper atmosphere) are excluded, over 65% of the total emission results from auto travel to and from the airport, about 3% of the trip. The lower right-hand portion of the figure shows this relationship in terms of pounds of pollutants per passenger-mile. The value that obtains for the automobile in 1969 is also shown for comparison. It can be seen that on a productivity basis, even if all emissions are considered, the aircraft emissions are an order of magnitude lower than automobile emissions.

With the continued Federal drive to reduce automotive emissions, and if recent Congressional action to force the development of a "pollution-free auto" by 1975 is successful, the comparative picture may change in future years. Although aviation can point to statistics such as those in Table 5.2 to indicate that aircraft contribute a small amount of the total pollution, the fact remains that if aviation is to grow to meet the potential demand, reductions in pollution must be evident to the public so new facilities (such as STOL/VTOLports) can be established.

It is interesting to note that the recent airline program to replace all burner cans on the JT8D engine (which powers the B-727, B-737, and DC-9) was brought about by public demand for elimination of smoke around the airports – a result of the very small particulate emissions. The aircraft figures shown for 1975 represent the sum of emissions assuming all JT8D engines are operated with the "smoke-fixed" burners instead of the original "bill of material" burners.

The information presented here is intended to place air pollution by aircraft in perspective as only one source, and not the principal source, of air pollution. This does not mean there should be a relaxation of efforts to minimize air pollution due to aircraft operations. On the contrary, as improvements are made to reduce pollution by other sources, increased efforts will be needed in civil aviation.

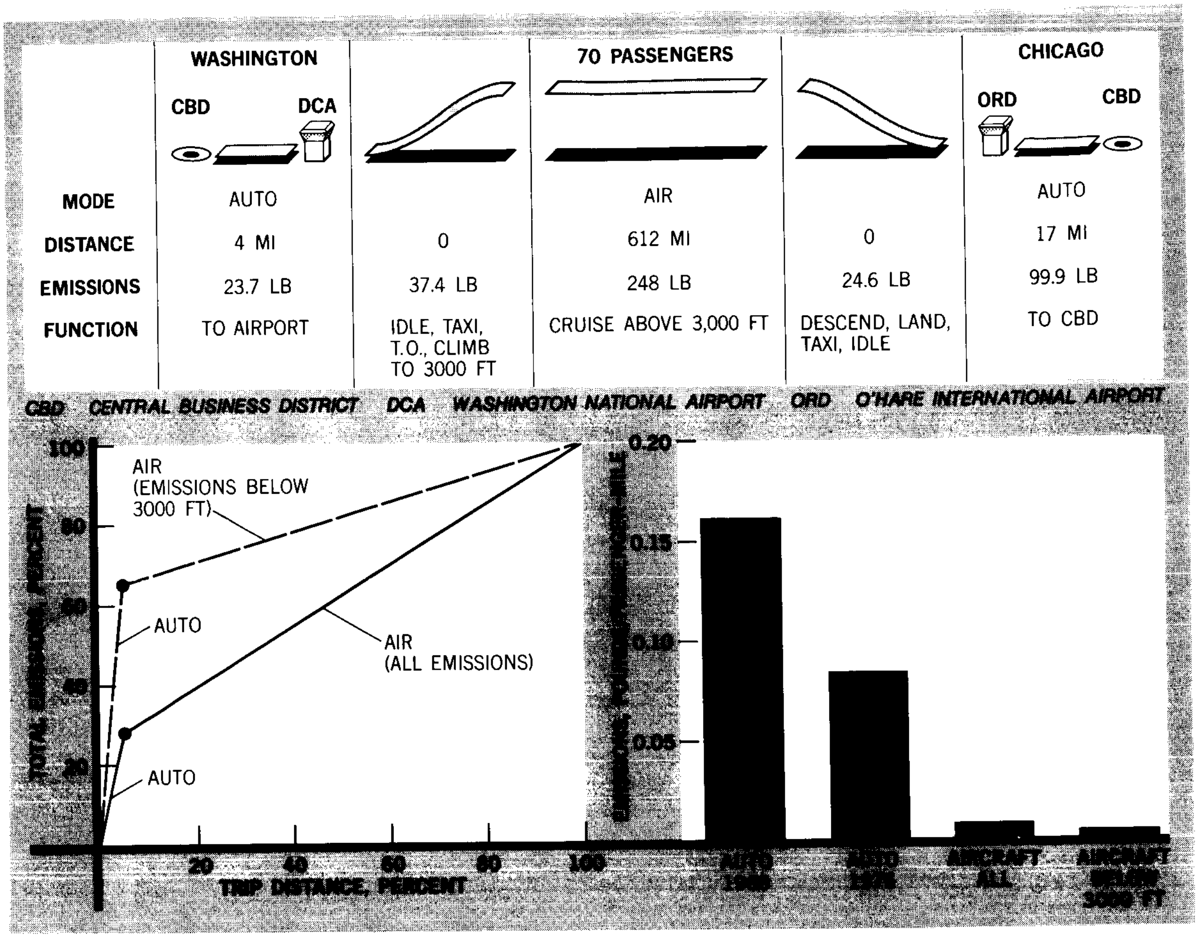

Figure 5.7. Air pollution – Washington to Chicago.

RECOMMENDATIONS

R&D programs continue to be needed urgently to improve aviation fuels and aviation engines, to lessen the amount of pollutants emitted, and to eliminate noxious emissions. A better understanding of the processes controlling engine emissions is needed. Better data on combustor conditions, especially species distribution, are needed to design minimum-emission combustors. Study and evaluation of the effect of aircraft emissions on the upper atmosphere should be continued.

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FINANCIAL CONSIDERATIONS

The U. S. aerospace and air transport industries are facing formidable financial difficulties. After an all-time net profit peak of $496 million in the 12 months ended September 1967, the U. S. certificated air carriers experienced a loss of about $150 million in 1970. The ATA estimated in December 1970 that the major carriers (domestic trunks plus Pan American) would have a loss of about $190 million in 1971. This estimate assumed that fares would not be increased (ref. 1). It should be noted that the airline industry has a net worth of approximately $3.4 billion.

The Business and Defense Services Administration estimated in mid-1970 that the value of shipments from aerospace manufacturers in 1970 would drop 15% below 1969 levels and 24% below 1968 levels. They also estimated that 1971 shipments would drop an additional 8.5% below 1970 levels (ref. 2).

Aerospace industry net profits after taxes at the end of the first quarter of 1970 were 2.3% of sales, compared to 3.5% for the same period in 1969. Reduced earnings will probably continue through 1971 because major firms have incurred higher debt loads due to high facility costs, unreimbursed Government program costs, and reductions in revenue-producing commercial sales (ref. 3). Equity-to-debt ratios are at an all-time low (in the third quarter of 1970, the equity-to-debt ratio for aircraft and parts manufacturing was 1.29, compared to 2.29 for all manufacturing corporations) (ref. 4).

The depressed general business situation during 1970, coupled with high interest rates, has made it difficult to finance purchases of new aircraft. For some time, the aerospace and airline industries have been unattractive for investors, although recent increases in prices of airline stocks may signal some improvement for the airlines.

BACKGROUND

Specialized air transport manufacturing and scheduled airline operations began in 1926 with the introduction of the Ford Tri-Motor and the passage of the Air Commerce Act. From the beginning, the economic health of both industries has been cyclical. Since 1926 no fewer than seven cycles of economic peaks and valleys have been recorded.

For the manufacturers, recovery from extreme financial difficulties has usually been accelerated by increased U. S. Government spending for R&D and for procurement of advanced military aircraft. It has become axiomatic that a strong commercial aircraft manufacturing base is essential to support the defense of the United States. In a period of lower defense budgets, a strong civil aeronautics industry would serve to sustain this very important industrial base.

Some of the factors that have contributed to the cyclical nature of the industry are discussed next.

External Forces

Some of the factors have been outside the control of the industry; for example:

- Three major wars – World War II, Korea, and Viet Nam.
- Six depressions, recessions, or "technical adjustments" – in 1929-1936, 1946-1948, 1953-1954, 1957-1958, 1960-1961, and 1970.
- Lags in Government actions to fit changing technological and economic levels (e.g., continuation of certain certification requirements for jet transports that were based on experience with reciprocating engines).
- The inflation from 1965 to 1970.

TABLE 5.4. TECHNOLOGY IMPROVEMENTS IN CIVIL TRANSPORT AIRCRAFT

AIRCRAFT TYPE	YEAR	IMPROVEMENT
FORD TRI-MOTOR	1926	ALL-METAL CONSTRUCTION, MULTI-ENGINE RELIABILITY
BOEING 247; DC-2; DC-3	1933-36	LONGER RANGE; HIGHER SPEED AND PAYLOAD; 14 ST ALUMINUM
DC-4	1945	HIGHER SPEED AND PAYLOAD; OVERWATER OPERATIONS; LONGER RANGE; FOUR-ENGINE RELIABILITY; 24 ST ALUMINUM
CONSTELLATION; DC-6	1946-47	HIGHER SPEED AND PAYLOAD; PRESSURIZATION; LONGER RANGE; HIGHER CRUISE ALTITUDE
SUPER CONSTELLATION; DC-7; DC-7C	1953-56	HIGHER SPEED, PAYLOAD, AND RANGE; TRANSCONTINENTAL FLIGHT TIME UNDER 8 HOURS; 75 ST ALUMINUM
VISCOUNT; ELECTRA	1955-59	TURBOPROP, LESS VIBRATION AND NOISE; HIGHER SPEED
B-707; DC-8	1958-59	JET POWER; SPEED; BETTER PASSENGER COMFORT; 7178 ST ALUMINUM
B-747	1970	WIDE-BODY CAPACITY; HIGH-BYPASS-RATIO ENGINES

Technological Advances

Over the years, eight distinctly different levels of technology have been introduced into scheduled airline service in the forms of landmark transport aircraft or engines (Table 5.4).

Each of these technological advances followed a period of research and development, largely funded by the U. S. Government. For example, each improvement was based on new power plants developed under U. S. Government auspices for military programs. Cabin pressurization, one of the major advances, was initially developed in the mid-1930's through Government-funded programs. (See also refs. 5 and 6.)

Attitudes, Practices, and Conditions Common to the Aerospace and Airline Industries

About 75 cents of every dollar spent in the production of commercial transports is for labor. Nearly half of the cash expenditures by the airlines are for labor. This high cash-flow requirement creates a supersensitivity to economic variations. As a consequence, the average profit margin on sales has been only 3.48% for the airlines, with a return on total investments of 6.9% since 1947 (first CAB-published data). A 2.4% margin on sales from 1941 through 1969 is recorded for the aircraft manufacturing industries (negative profit years counted as zero), as compared to 5.4% for all manufacturing industries over the same period. Figures 5.8 and 5.9 show selected financial trends for the airlines and for the aircraft manufacturing industries.

The increasing size, complexity, and higher technology levels of new transport aircraft are causing the cost of development, production, and testing to become larger than any one U. S. manufacturer's financial capability. Both the aircraft and airline industries have required large debt-financing to continue to build or purchase advanced transport aircraft. This introduces an important noncontrollable, nonoperating expense that is seriously affecting the profits of both industries. Figure 5.10 shows the increase in total investment and the attendant increase in interest on the long-term debt incurred by the airlines in the past 20 years. Figure 5.11 shows the amount of long-term debt financing of major aerospace companies since 1937 as a percent of total

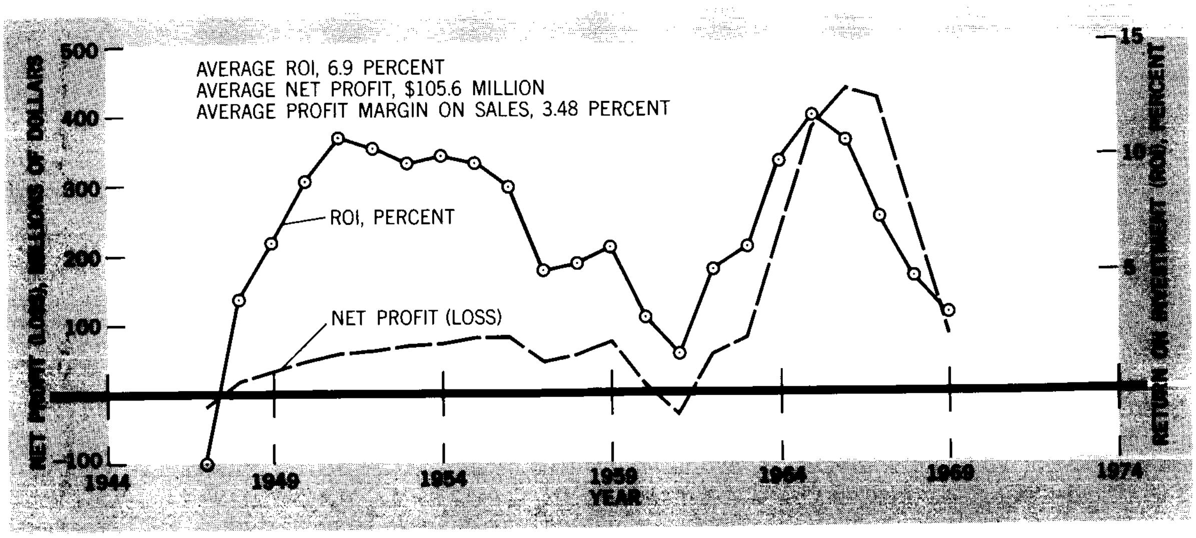

Figure 5.8. Total U. S. certificated route air carriers' return on investment and net profit/loss: 1947-1969 (annual). *Source: Ref. 7.*

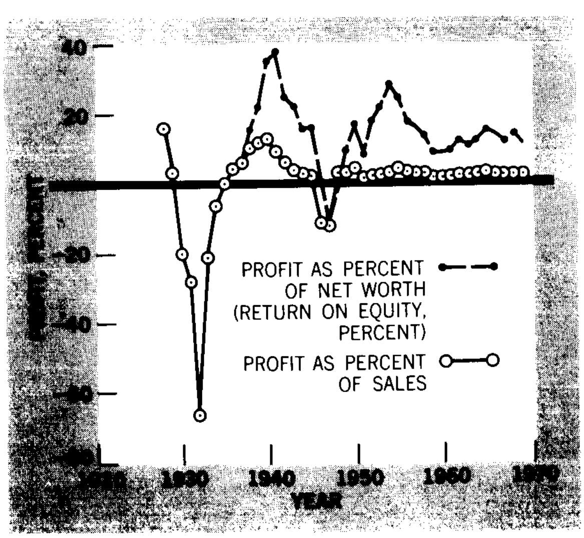

Figure 5.9. U.S. aircraft industry's profit as percent of sales and percent of net worth (return on equity). *Source: Ref. 8.*

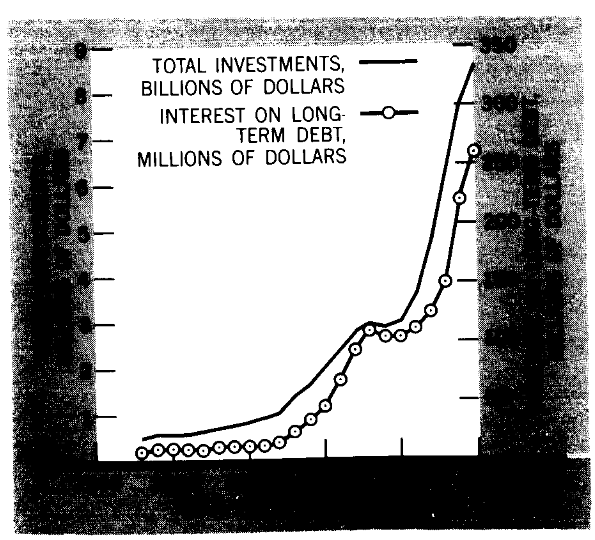

Figure 5.10. Total U.S. certificated route air carriers' total investments and interest on long-term debt; 1947-1969 (annual). *Source: Ref. 7.*

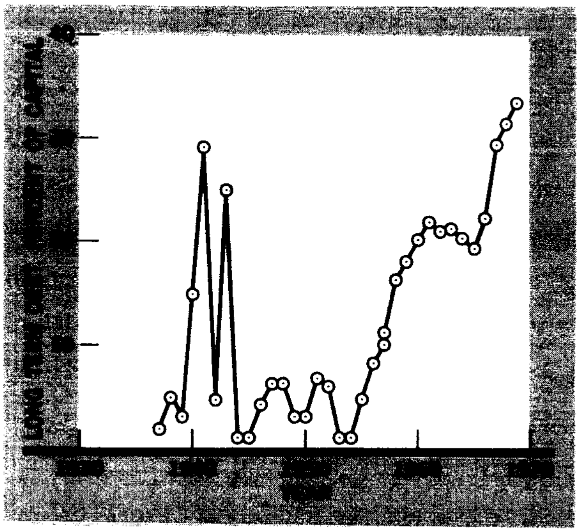

Figure 5.11. U. S. aerospace industry's debt financing as percent of total capital. *Source: Ref. 8.*

TABLE 5.5. AIRCRAFT DELIVERED OR ON ORDER, DOUGLAS AIRCRAFT COMPANY, JUNE 1970

TYPE	NO. DELIVERED OR ON ORDER	NUMBER OF AIRLINES
DC-9-10	103	19
-10MC	5	1
-10RC	19	1
-20	10	1
-30	401	37
-30AF	6	3
-30CF	7	2
-30RF	10	2
-40	24	2
C-9A	12	1 (USAF)

Source: Ref. 9.

capital. Debt-servicing expenses for the aerospace industries over this period are not readily available.

Attitudes and Practices Peculiar to the Aircraft Industry

Although civil transport aircraft may be built in large quantities, they are tailored to each customer's desires. As an example, Douglas Aircraft Company reported in June 1970 that 597 DC-9's had been delivered or were on order (ref. 9). A breakdown of the types, number delivered or on order, and number of airlines is shown in Table 5.5

Although these aircraft are of the same basic design, they vary greatly in detail. The airlines demand different cockpit arrangements, different galley arrangements, different lavatory arrangements, and different cabin interiors. As a result, the aircraft become "custom jobs," the economy of large-scale production is not achieved, and costs are significantly increased.

Because the competition is intense, an aircraft manufacturer will rarely turn down an order, even though a special requirement might disrupt planned and efficient production flow. The manufacturer therefore incurs higher costs for tooling, facilities, training, etc., than he would if an orderly and even production line were maintained.

The aircraft manufacturing industry has become so large that some companies have not maintained an economical control of programs. Engineers tend to make unnecessary changes and improvements in design without due consideration for program costs. Often, "advancing the state of the art" has created unnecessarily high costs because of more sophistication, greater complexity, and increased requirements for testing. Engineering departments sometimes become overspecialized as the older "generalist" type engineers retire. An attendant loss of communication among the several design disciplines can result in unnecessary costs.

Attitudes and Practices Peculiar to the Airline Industry

The Civil Aeronautics Board (CAB) is frequently blamed for the overcapacity, low revenue

yields, and excess competition in the airline industry. It can be argued, however, that the CAB merely reacts to requests submitted by the airlines for approval of specific actions. No one forces the airlines to apply for new routes that are already adequately served. However, the CAB has to consider the airline or airlines already serving the particular routes, and as CAB Vice Chairman Whitney Gillilland said in November 1970, "It is possible there has been a tendency to be more liberal in resolving doubts in favor of the expansion of competition than the facts have justified" (ref. 10). It may well be that the airlines would not want elimination of Government regulation, since the regulatory agencies represent impartial bodies to turn to in times of stress.

The effect of price elasticity on traffic and profits is still not accurately known. The Air Transport Association stated recently:

> The decline in yield (6.24¢ per passenger-mile to 5.34¢ in 1968) resulted mainly from the host of discount and promotional fares introduced by the scheduled airlines throughout this period. The Civil Aeronautics Board would not permit airlines to alter the downward trend in unit prices until it became almost too late (ref. 1).

Nevertheless, the airlines decided that this 15% decrease in average yield per passenger-mile was advantageous. Commenting on promotional or developmental fares at the IATA Annual General Meeting in Teheran (October 27, 1970), Ian Sinclair, Chairman of CP Air (formerly Canadian Pacific Airlines, Ltd.), said:

> Development rates are common to most transport media. The logic is simple – establish rates at an artificially low level to encourage a particular market to develop and then increase rates to a fully compensatory level. By doing so, the argument runs, you build up markets and ensure profitability in the long term. A very convincing argument – except that it never works quite that way. Development rates become sticky on the upside and it never seems to be quite the appropriate time to increase them. Development goes on and maturity is never reached. Nor is a profitable transportation operation ever achieved. . . . I can see it happening now in airline pricing and I must express my concern (ref. 11).

Although promotional or development rates have been used often, there is a serious lack of data to show the effect of such rates on traffic and profits. Decisions on the use of promotional rates are thus based on qualitative judgements rather than quantitative data. Some experiments are needed. Studies of the effect of various stages of deregulation should also be made.

The lessons of history are often not fully utilized in planning for the future. This can be illustrated by a comparison of a quote from the Air Transport Association and the actual annual growth rates reported to the CAB by U. S certificated route air carriers, as shown in Figure 5.12. The important point is that "historical trends" referred to in the quote were obtained by examination of the period 1963 to 1967. Thus, many airline decisions were based on consideration of a short period that showed a constant or increasing growth rate. Consideration of a longer time span, showing the impact of such uncertain factors as recession or inflation might have tempered some of the decisions.

It appears reasonable to plan for a period of some overcapacity following the introduction of new, larger aircraft, such as the wide-body jets. This overcapacity can be desirable from the standpoint of attracting additional passenger demand. However, this expected overcapacity, coupled with such fluctuations as shown in Figure 5.12, can result in severe financial difficulties. It is obvious that the airlines must conduct rigorous analyses of future requirements before committing to the purchase of aircraft in quantities.

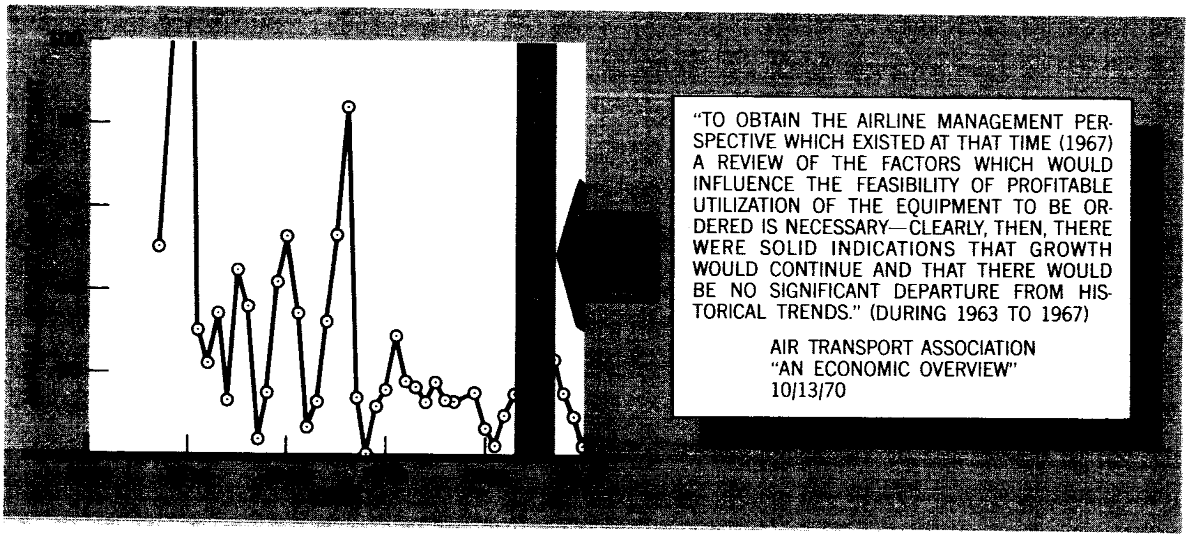

Figure 5.12. Annual growth rate of total U. S. certificated route air carriers' revenue passenger-miles.

All segments of the traveling public are not paying their share of operating costs. The long-haul, high-density routes have subsidized the short-haul, high-cost routes. In 1968, in the continental United States, 65% of all flight stage lengths were less than 300 miles, although only 34% of all passengers made trips of less than 300 miles. Many factors affect short-haul economics (see "Commercial Passenger Service" section), but one problem (or result) is that U. S. aircraft manufacturers have not yet produced an aircraft that operates profitably in short-haul operations. Airlines have tended to use their older and depreciated aircraft on short hauls in hopes of cutting losses. This has never been financially successful.

CONCLUSIONS

- Both the aircraft manufacturers and the airlines are experiencing the severest financial difficulties in their history.
- These difficulties have been encountered several times in the past. Historically, recovery of the manufacturing industry has been accelerated by U. S. Government R&D, plus procurement contracts.
- The increasing size, complexity and higher technology levels required for new transport aircraft are causing development costs to become larger than any one U. S. manufacturer's financial capability.
- Both the aerospace and the airline industry have incurred large long-term debts which seriously affect their profits.
- U. S. airlines are hard pressed to obtain financing for the purchase of new and advanced aircraft.
- Disruptive instabilities in the aerospace industry and in its civil markets must be alleviated in the national interest.
- Government-guaranteed loans for new development programs and for aircraft purchases would contribute to financial stability in the aviation industries.
- The effects of fare changes on traffic and on profits are not well known. Studies are needed to determine the effects of government regulation of fares and competition on the airline industry.

RECOMMENDATIONS

Impartial, in-depth studies are needed to determine the probable effects of a wide range of possible Government actions. The studies should include, but not be limited to, the effect of:

- "De-regulating" completely or, in part, airline routings and fare structures. This would permit the "free market" to determine the future posture of the air carrier industry.
- Permitting competition to continue but under further restraints, such as allowing no more than two airlines to compete between most city pairs.
- Establishing the airlines completely as public utilities. Implicit in this arrangement would be virtually guaranteed profits rather than the present "target" rates of return, plus increased regulation of activities.

In addition, it is recommended that the following actions be considered, as measures to increase the capability of, and the options for, financing the development and purchase of new air transport systems.

- Government financial underwriting for U. S. manufacturers, with payback and profit to the Government through royalties as aircraft are sold.
- Government-guaranteed loans for purchase of aircraft by the airlines. Under such arrangements the private sector could be more liberal in commitments for large, longer term loans. Precedents have been set for such actions; the ICC was permitted to guarantee loans for the railroads; DOT is authorized to guarantee loans to local, feeder, and short-haul airlines (ref. 12).
- Reintroduction of the investment tax credit for the purchase of new air transport systems. Such financial support could stimulate new developments.

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FOREIGN COMPETITION

BACKGROUND

Since World War II, the U. S. aircraft industry has enjoyed the dominant share of the aircraft market in foreign countries and has had relatively little competition from abroad for the market in the United States. One of the principal reasons for this success has been the technical, production, and economic superiority of U. S. aircraft and parts.

This superiority was due in great part to the large bank of available R&D data that existed at the end of World War II and which the commercial aircraft and component manufacturers were able to develop quickly and economically into commercial products. The U. S. Government sponsorship of R&D efforts began to increase significantly long before World War II when it was realized that the United States was falling far behind European countries in aeronautical technology.

Foreign concerns and governments are now concentrating greater technical, financial, and political efforts on capturing world aviation markets. They seek to become less dependent on the United States for commercial and military aircraft, and hope to gain a significant share of the U. S. domestic market.

Another significant reason for the superiority of U. S. commercial aircraft products is the domestic competition that has existed among the major U. S. aircraft manufacturers for the U. S. airline market, the major market for two decades following World War II. In addition, the sale of U. S. aircraft overseas has been aided by the "total-package" approach. Training, spares, repairs, full-time service personnel, and some financing are generally provided with the aircraft. Under this approach, a wide spectrum (or "family") of aircraft has also been developed to fit the varying needs of airlines. But now aircraft industries in Western Europe and Japan have sufficient strength to begin to offer the same "total package" as U. S. manufacturers. In some cases they are outbidding U. S. concerns, particularly with respect to financing. As a result, U. S. industry may have to accept a significantly smaller share of the world market.

U. S. AIR CARRIER COMPETITION FOR INTERNATIONAL MARKETS

Airline passenger traffic is expected to grow about five times between 1970 and 1985 throughout the free world (Table 5.6). The U. S. share of this traffic cannot be expected to grow proportionally. Foreign-flag air carriers are overcoming the economic setbacks of World War II and are extending their routes into markets previously served almost exclusively by U. S. carriers.

In international transportation, foreign carriers have grown more rapidly than the U. S. carriers in recent years. To reduce cost, inter-airline consortia have been formed to standardize equipment, reduce maintenance and training costs and spare parts inventories. In addition, they are maintaining a competitive position by buying the most modern equipment. They can, however, no longer be considered captive markets for U. S. air transport equipment. Improvement in the margin of technical and economic superiority, coupled

TABLE 5.6. FORECAST OF FREE–WORLD AND U. S. SCHEDULED PASSENGER–MILES AND U. S. SHARE OF TOTAL

PASSENGER-MILES IN SCHEDULED SERVICE	1970	1975	1980	1985
TOTAL FREE WORLD, BILLIONS	242	460	800	1,300
U.S. DOMESTIC AND INTERNATIONAL, PERCENT OF FREE WORLD	57	54	52	50

with liberalized financing terms, should assure the continued sales of U. S. equipment abroad.

Foreign governments are also moving to strengthen their aircraft manufacturing industries by encouraging the formation of multinational consortia. While U. S. companies are also acquiring foreign partners, it seems likely that the foreign consortia have more to gain than the United States from internationalization.

U. S. SALES OF AVIATION PRODUCTS IN FOREIGN MARKETS

With the introduction of the DC-3 in 1936, American-made aircraft began to establish a strong position in world markets. In 1958, 83% of the transport aircraft in operation in the free world were of American manufacturer (ref. 1). That proportion has declined but, supported by the world-wide popularity or American-made jets, it is still about 76% (ref. 2).

The advantage which the United States has enjoyed as a result of transforming a large technology base into commercially attractive products is declining at an accelerating rate as foreign manufacturers strengthen their aviation industry. It is essential that research and development efforts in this country – specifically directed toward civil aviation requirements – be increased if U. S. preeminence in world aviation markets is to be maintained. In addition, aid to assure that U. S. manufacturers are able to offer financial terms at least as attractive as their foreign competitors, is essential.

Foreign manufacturers are quite familiar with the technologies currently used by U. S. airplane and component manufacturers. Furthermore, their governments are assisting them by underwriting innovative R&D programs. Some foreign-built aircraft and items of equipment have already attained a quality equal or superior to products from the United States. A few examples of technical equality include:

- Vickers VC-10 jet aircraft
- Rolls-Royce turbine engines
- Nihon YS-11 turboprop aircraft
- Numerous avionic items
- All-weather operating equipment

Examples of foreign superiority are:

- Lift engines
- Cold-weather operating equipment and techniques employed by Canada, Sweden, and the U.S.S.R.
- V/STOL aircraft

Foreign purchases of U. S. civilian-type aviation products (e.g., aircraft engines, parts, and accessories) accounted for about 35% of the industry's sales from 1958 to 1969 (ref. 1). A major U. S. airframe manufacturer estimated in 1970 that the combined dollar value of passenger and cargo aircraft required by the world's airlines from 1970 through 1980 will be about $88 billion – $52 billion for the United States and $36 billion for foreign suppliers (ref. 2). This forecast indicates that the ratio between domestic and foreign sales may be expected to continue over this decade. The increasing size and complexity of future transport aircraft and the resulting increase in the cost of development, construction, and testing may exceed any single manufacturer's financial capabilities. Financial commitments presently facing the three major U. S. transport airframe manufacturers (Boeing, Douglas, and Lockheed) are several times their combined net worth ($1.43 billion reported in 1969 (ref. 3)). McDonnell Douglas Corporation, for example, had a net worth of $315 million in 1969. By the time the first DC-10 is delivered to an airline in 1971, the net worth is estimated to be $400 million, but the company will have invested $1.25 billion in that program (ref. 2). Indications are that Boeing and Lockheed face similar situations with the 747 and the L-1011 programs.

Foreign airlines have become much more demanding than in the past with regard to financing terms for the purchase of U. S.-built aircraft and equipment. In addition to direct loans and subsidies to their manufacturers, foreign governments have shown willingness to support their industry marketing efforts by means of attractive financing arrangements, including longer payback periods than those legally permitted by the U. S. Export-Import Bank. They have also adopted practices eliminating requirements for supplier financial participation and for guarantees from the government of the purchaser; in some cases, they are also providing substantially lower interest rates.

Since 1945, the Export-Import Bank of the United States has been the principal lending institution participating in the financing of U. S. export products. It has made outstanding improvements within the past two years in arrangements for financing U. S.-built commercial transports for foreign airlines. The Bank, however, is handicapped by certain statutory and procedural factors. It is restricted by a statutory limitation to $13.5 billion for export financing (refs. 4 and 5). In addition, in 1968 the Bank was brought into the Federal Government's "Unified Budget" process, requiring it to operate under an annual appropriation procedure, thus reducing its ability to operate as a separate profit-making entity.

Despite the Export-Import Bank's active participation in the initial round of wide-body tri-jet ordering, the highly competitive situation permitted the foreign airlines to demand and secure increased financial participation from U. S. manufacturers. This required the manufacturers to obtain additional financing from private and expensive sources to make up for the limitation in Export-Import Bank participation. Today many foreign governments offer much better terms for the purchase of aircraft equipment. The U. S. is likely to meet increasingly stiff competition in financing. The annual appropriation process of the Export-Import Bank compounds the problem of lending because aircraft financing is inherently long term.

The value of the aerospace industry to U. S. export trade is illustrated by Table 5.7.

TABLE 5.7. U. S. AEROSPACE INDUSTRY CIVILIAN AND MILITARY EXPORTS AND IMPORTS, 1969 (IN MILLIONS OF DOLLARS)

ITEM	EXPORTS			IMPORTS TOTAL
	CIVIL	MILITARY	TOTAL	
AIRCRAFT	1,236	618	1,854	104
ENGINES	102	51	153	31
ACCESSORIES, ETC.	610	377	987	171
MISSILES, ETC.		157	157	
TOTAL	1,948	1,203	3,151	307

Source: Ref. 1.

The aerospace contribution toward a favorable balance of trade in 1969 was $2.8 billion. The net balance of trade for the United States in 1969 was only $1.6 billion. Between 1965 and 1969, the aircraft industry contributed 58.9% of the total favorable balance of trade, with civil aircraft contributing 34.6% (ref. 2).

The economic importance of the foreign markets for the U. S. aircraft industry lies not only in generating a favorable balance of trade but also in providing the major source for potential profits and longer production runs, resulting in lower manufacturing costs. This is reflected in lower aircraft and equipment costs and in lower operating costs for U. S. airlines.

General Aviation

General aviation aircraft form a foundation for all civil and military aviation activities. Nearly all pilots first learn to fly in this type of aircraft. General aviation is the fastest growing category of aviation products in the world market. Its growth has been stimulated by an increasing realization

of the value of discretionary mobility and speed offered by general aviation aircraft.

As with transport aircraft, U. S. manufacturers of general aviation aircraft in the past have dominated the world market, largely because of technical superiority, pricing policies, marketing techniques, and aftersales support of their products. Foreign manufacturers are now, however, providing real competition to U. S. export and domestic sales.

The potential of the general aviation aircraft market can be seen in Table 5.8. The data for the year ending 1969 are for licensed aircraft in active use. The free-world forecasts for 1975 and 1980 are based on growth trends as published by the International Civil Aviation Organization (ICAO) in May 1970 (ref. 6). The forecasts for the United States were made by the FAA in January 1970 (ref. 7).

Between 1960 and 1969, the U. S. general aviation industry increased its annual export units from about 1,500 with a value of $47 million, to 2,500 units, with a value of $150 million. The total exports of general aviation aircraft from 1960 through 1969 were 20,512 units, with a value of $990.5 million.

During this same decade, foreign manufacturers of general aviation aircraft increased their annual export sales from about 200 units to nearly 900 units. The value of these exports has increased from some $5 million to $125 million annually.

The value per unit exported by both U. S. and foreign general aviation manufacturers has also increased significantly. This trend is expected to continue. In 1960 the average value per general aviation aircraft unit exported by both foreign and U. S. manufacturers was about $30,000. In 1969, however, while the average value per unit exported by U. S. manufacturers had increased to approximately $63,000, the value for foreign-manufactured exports had risen to about $140,000 per unit. This seems to indicate that foreign manufacturers are concentrating more on sophisticated business aircraft than on personal or pleasure aircraft. Because of increasing foreign competition in the decades ahead, the U. S. share of the total free-world general aviation fleet is expected to drop from 79% in 1969 to about 64% by 1980.

CHANGING WORLDWIDE COMPETITIVE CONDITIONS

Most free-world governments now recognize the great value of civil aviation activity, both manufacturing and operating, as an instrument of national and regional policy. Accordingly, they are providing direct financial and political support to developments that benefit their civil aviation

TABLE 5.8. FORECAST OF NUMBER OF FREE–WORLD AND U. S. GENERAL AVIATION AIRCRAFT

PERIOD	TOTAL FREE WORLD	UNITED STATES	FREE WORLD, EXCLUDING UNITED STATES
1969 FLEET, ACTUAL	177,258	130,118 [a]	47,140
1975 FLEET, PROJECTION	260,400	178,000	82,400
1980 FLEET, PROJECTION	350,400	225,000	125,400

[a]*Number actually used and flown as distinguished from the number of eligible aircraft (130,806). As shown in other sections of this report, the number at the beginning of 1969 was 124,237.*
Source: Based on refs. 6, 7.

activities. British and French Government contributions for research, development, and production facilities for the Concorde, for example, will exceed $2 billion. Financing for the European consortium A-300 airbus seems assured and involves backing by governments of the European Economic Community of about $400 million. Now that the British Aircraft Corporation twin-engine, wide-bodied airbus (BAC 311) has been dropped, the other partners in the European Economic Community are pressing the U. K. Government to participate in the A-300 program. Without official participation by the Government of the United Kingdom, the Hawker Siddeley Company has invested about $35 million of its own private capital in the A-300 program.

The Japanese Government is also strongly supporting the development and expansion of its civil aviation activities. In addition to continuing production of the standard YS-11 twin-engine turboprop transports, Nihon Aeroplane Manufacturing Company is now offering, with government backing (up to 100% of the net worth of the company), four-engine turboprop STOL and twin-engine jet versions of this aircraft. The 60-seat twin-jet version YS-11J is being offered at a price slightly over $2 million delivered in the United States, with very liberal financing terms. There is no comparable U. S. product being offered, although at least four U. S. local service airlines have expressed more than casual interest in this program. Nihon Manufacturing is also developing, with government backing, the 100-plus passenger tri-jet YS-33. It is expected to be operational by 1974 and will be directly competitive with the DC-9, B-737, and B-727 aircraft, particularly on the mainland of Asia. Boeing is considering entering into a joint program with Nihon to build a 200-seat airplane. American manufacturers may look increasingly for a low-cost labor market in the future to be able to compete more effectively for the short-haul market.

In the postwar years, American manufacturers enjoyed an assured U. S. domestic market of sufficient size to break even on development, manufacturing, and testing costs on almost all new aircraft introduced. Export sales were the major source of profits. In contrast. European builders have been restrained by the realization that they could expect to break even on a new aircraft only if substantial export sales could be achieved. In the face of tariff and other trade barriers, and severe American competition, they were seldom inclined to take the risk. Furthermore, their inadequate capitalizations and management policies resulted in protracted development times which allowed the United States to capture the bulk of the market, as in the cases of the 707 and DC-8 versus the VC-10. The formation of consortia will undoubtedly relieve many of these constraints. Concurrently, the reduction of trade barriers among the European partners will confer significant advantages on their own aircraft vis-a-vis American models.

The impact of foreign government participation in the manufacturing, marketing, financial, and political aspects of the air transport industry is increasing at an accelerating rate. The percentage of all transport aircraft of U. S. manufacturer flown by airlines of the free world has declined during the past 10 years. The continuing trend of penetration by foreign transport aircraft is evident. Normally, 63% of the total foreign fleets have been of U. S. manufacturer, but aircraft on order from U. S. manufacturers has fallen to 59% (ref. 8). Table 5.9 shows the U. S. manufacturers' share of the free-world aircraft fleet and aircraft on order as of December 31, 1969. Although the difference in the number of aircraft is not yet great, the avowed intent of foreign manufacturers and governments, if inadequately countered by the United States, will significantly change the fleet composition.

Foreign Sales of Aviation Products in the United States

U. S. airlines have paid deposits to ensure delivery positions on 38 Anglo-French supersonic Concorde transports valued at over $900 million.

TABLE 5.9. FREE–WORLD AND U. S. FLEET SIZE AND AIRCRAFT ON ORDER AS OF DECEMBER 31, 1969

FLEET STATUS	AIRCRAFT	
	NO.	PERCENT
PRESENT FREE-WORLD AIRLINE FLEET SIZE	6,711	
U.S. MANUFACTURERS' SHARE	5,086	76
TOTAL ON ORDER (UNDELIVERED)	1,166	
U.S. MANUFACTURERS' SHARE	899	77
U.S. AIRLINES FLEET	2,736	
U.S. AIRLINES FLEET OF FOREIGN MANUFACTURERS' AIRCRAFT	174	6
FOREIGN AIRLINES FLEET	3,975	
FOREIGN AIRLINES FLEET OF U.S. MANUFACTURERS' AIRCRAFT	2,524	63
U.S. AIRLINES ON ORDER, TOTAL	608	
U.S. AIRLINES ON ORDER FROM FOREIGN MANUFACTURERS	38	6
FOREIGN AIRLINES ON ORDER, TOTAL	558	
FOREIGN AIRLINES ON ORDER FROM U.S.	329	59

Source: Ref. 8.

Flight simulators from the United Kingdom, valued at over $20 million, are being placed in service by U. S. airlines. Canada and Italy are making major assemblies for McDonnell Douglas transports, and if the current financial crisis at Rolls-Royce can be resolved, it may still supply the engines for the Lockheed L-1011 transports.

Unless competing U. S. aircraft are developed soon, the Japanese may make significant inroads into the U. S. short-haul CTOL markets with their economical YS-11's. These requirements are currently served mainly by obsolete aircraft, some of which have been modified to turboprop versions. The YS-11 has been fully accepted by the operators and traveling public as an excellent aircraft. If the A-300 wide-body twin-engine airbus program is successful in excluding competing U. S. products from Europe and European areas of influence, it is entirely possible that a large portion of the U. S. requirement for this type of aircraft (estimated by a major airframe manufacturer to be about 600 aircraft worth $8 billion in the next decade) could be filled by foreign-built aircraft. If the foreign market potential is seriously reduced, U. S. manufacturers will be reluctant to compete on a marginal profit basis.

Most STOL aircraft developments are in Europe and Canada, and more recently in Japan. A recent aeronautics study for the Science Council of Canada recommended that the Canadian aircraft industry concentrate on the development of V/STOL systems, with Government financial and facility assistance for the necessary R&D (ref. 9). If VTOL and STOL short-haul interurban system development is delayed any longer in the United States, foreign manufacturers will have a competitive edge which will adversely affect the U. S. share of the total market.

Competitive Trends

The Transportation Products Division of the U. S. Department of Commerce has noted the following trends:

- Production consortia are emerging as a key hope for European aerospace companies to generate a strengthened competitive posture vis-a-vis U. S. manufacturers in the world market.
- During the next two decades the demand for aircraft by European airlines and military forces will be very large. If these aircraft are manufactured mainly outside Europe, the European balance of trade will be seriously handicapped. Another factor dictating the further development and strengthening of the European aircraft industries is the stimulus that the aircraft industry provides to many allied industries, such as electronics and computers, which helps Europe to continue to be a leader in the advanced technologies.
- The U. S. wide-bodied tri-jets, along with the Boeing 747's, are being sold world-

wide. Of the some 700 DC-10's that McDonnell Douglas expects to sell by 1983, between 300 and 400 will be purchased by foreign carriers. Lockheed's forecasts are similar and foresee that about 200 L-1011's will be sold in Europe alone by 1980. Both companies, as well as General Electric, acknowledge a trend toward "quid pro quo accords" in international aircraft sales, meaning that U. S. manufacturers wishing to sell aircraft abroad will find it advantageous to arrange for manufacturing participation by the countries involved.

With regard to the last point, advanced U. S. technology, such as titanium structures, can help the United States maintain its leadership by keeping virtually 100% of the production program for new U. S. aircraft confined to U. S. plants. This can combat the increasing tendency for foreign buyers to demand "offset agreements" on the production of aircraft based on existing technology which substantially decrease U. S. balance-of-payments posture in foreign sales.

The introduction of the A-300 European wide-body twin-engine jet will make inroads into the U. S. wide-body tri-jet market. More importantly, the A-300 would be in direct competition with possible twin-engine derivatives of the U. S. tri-jets.

Although the U.S.S.R. has not been a serious competitor in the free-world international air transport market, its fast-improving technology and strong desire to enter this field could make it a strong contender before 1985. The U.S.S.R. was officially accepted recently as a member of the International Civil Aviation Organization (ICAO). This membership is a first and vital step towards the recognition of Russian transport and other civil aircraft by the free-world's certification bodies. Three 30-seat Yak-40 tri-jets were recently sold (on a barter basis) to the airline in Afghanistan for $500,000 each, with an interest rate of 1-1/2%, and repayment in 30 years.

In anticipation of competing in the U. S. market with the Yak-40, the U.S.S.R. is expressing willingness to equip the aircraft with U. S.-built engines and with U. S. avionics products, a direct reversal of its previous position. Significant improvements in the quality of its sales brochures, its willingness to exchange technical information, and greatly improved product-support planning is further evidence of the seriousness of its intent to penetrate the market. Other civilian aircraft already flying and being offered for sale to free-world airlines by the U.S.S.R. include:

Tu-144, supersonic transport (Mach 2.3)
Il-62, four turbofan engines, 180-passenger, similar to the VC-10.
Tu-154, three turbofan engines, 150-passenger, similar to the B-727.

The Russian airline Aeroflot has been increasingly interested in worldwide acceptance and has recently requested membership in the International Air Transport Association. This is the first step toward entering the competitive market in world airline travel.

CONCLUSIONS

- The United States is facing rapidly increasing competition from foreign airlines and aircraft/component manufacturers. This competition is challenging U. S. leadership in the commercial aviation industry, particularly through foreign government support and financing of their aircraft/component manufacturers. Private U. S. companies with their large but limited financing capacity will find it increasingly difficult to stand up to foreign government supported competition.
- Coincident with this emerging foreign competition, the U. S. aerospace industry is losing its financial and technical vitality due to reduced financial ability of U. S. airlines to purchase new equipment and to large cost increases. These factors

have weakened the industry's capacity to challenge the new foreign competition.

- It will require cooperative efforts by the U. S. aerospace industry and the U. S. Government to assure that the aircraft export markets are not lost.
- The United States has maintained its leadership position by translating a substantial technological base into highly desirable products. The heavy emphasis on development, coupled with superior production techniques and after-sales servicing, have been key factors in the attainment of this leadership position.

RECOMMENDATIONS

- Concentration on strengthening the domestic market will keep the civil aviation industry favorably competitive in world markets. Therefore, it is recommended that joint Government-industry efforts particularly concentrate on the development of quieter, cleaner, and more efficient engines, and the development and demonstration of STOL/VTOL vehicles and short-haul systems.
- If military procurement of vehicles should decrease, an important source of production "know-how" will dissipate. It will be important to initiate R&D on production techniques to make up for any significant decrease in the volume of military-vehicle manufacturing.
- Greater flexibility of company-sponsored research and development programs, in the form of recognizing them as allowable expenses (IR&D), under Government contract should be encouraged.
- The capability of private lending institutions and the Export-Import Bank to offer more attractive financing for export sales should be increased by:
  - Increasing the statutory limit of $13.5 billion on the Export-Import Bank to at least $20 billion to reflect the increased costs of new civil aviation exports.
  - Increasing the participation allowances of the Export-Import Bank financing to the previously permitted level.
  - Dissociating the receipts and disbursements of the Export-Import Bank from the budgets of the Federal Government and exempting such receipts and disbursements from limitations on annual expenditures and net lending.

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MILITARY CONTRIBUTIONS TO CIVIL AVIATION

INTRODUCTION

It has been suggested (ref. 1) that military R&D in the future will be of less benefit to civil aviation because of a divergence between civil and military aeronautical requirements. On further consideration of this question, one of the points explictly covered by the Senate Committee on Aeronautical and Space Sciences in recommending that the present study be made was that the "study might also include a detailed analysis of the divergence of military and civilian aeronautical requirements in order to assess better the diminishing benefits to civil needs from military R&D" (ref. 2).

CHARACTER OF MILITARY AERONAUTICAL R&D

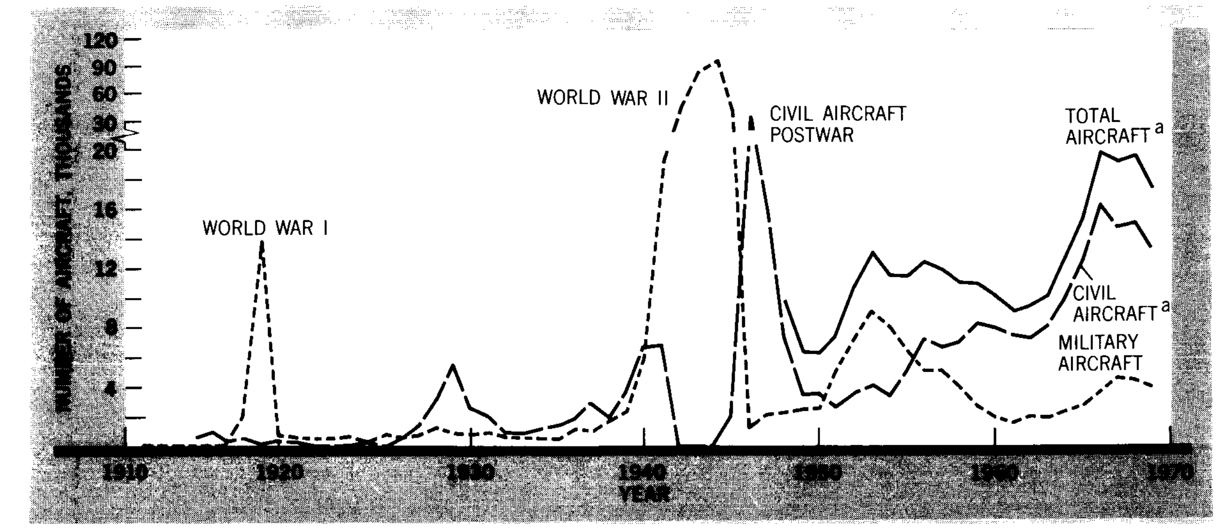
Military R&D is basically oriented toward the development of complete weapons systems to support national defense. Recognizing this crucial necessity for technologically superior weapons, the Congress provided for the Department of Defense (DOD) to engage in R&D on weapons systems and other military requirements. Thus, military R&D programs in aeronautics are aimed toward the solution of military problems and *not* to the direct support of civil aviation R&D. However, the aeronautical technology produced for military programs in the aircraft industry is generally available for use in civil aviation applications, except for limited national security exclusions.

HISTORICAL FACTORS IN AVIATION DEVELOPMENT

From the days when the World War I Handley Page bomber was converted to a commercial transport to the present-day thrust into the supersonic regime, military aircraft have often paved the way for advances in commercial aviation. The basic necessity for the development of technologically superior weapons has contributed to the rapid rate of aircraft obsolescence, which, along with commercial competition, has stimulated aircraft design changes within the aviation industry. Thus, the design competitions of prototype aircraft for military aviation have frequently provided an impetus to better performance of civil aircraft (ref. 3). For example, even the casual observer readily detects a similarity in the present-day commercial jet transport to the B–47, B–52, and KC–135 military aircraft. Also, military R&D programs have led to the design and production of many of the basic aircraft engines that have been used in commercial aircraft (ref. 4).

A review of the growth of the aircraft industry in the United States leads to the observation that the industry's development has also been influenced largely by factors peculiar to specific time periods (ref. 5). Figure 5.13 shows the impacts starting with World War I and the production of 13,991 military aircraft in 1918 (ref. 6). While this aircraft production, sparked by the Liberty engine of 1917, was of little significance in the overall war effort, it did establish the beginning of the U. S. aircraft industry. The boom in civil aircraft demand, highlighted by Lindberg's flight in 1927 was short-lived; the sharp falloff in this early demand for civil aircraft was coincident with the depression. The industry's founders did recognize, however, the need for establishing national policies directed toward developing commercial aviation as a necessary element for dynamic growth of the industry. The sustaining effect of Government contracts for producing military aircraft and carrying mail also affected the future structure of the industry.

The modern civil airliner was born in 1933 when early twin-engine transport prototype aircraft, such as the Boeing 247 and the Douglas DC–1, made their initial flights (ref. 7). These were the first transport aircraft designs offering the commercial aviation passenger the promise of speed, reliability, and comfort with upholstered, fitted seats and balanced acoustic cabin designs. By 1940, the four-engine Boeing



a Noncumulative

Figure 5.13. U. S. aircraft production, all types. *Source: Ref. 6.*

Stratoliner, the first pressurized airliner, was carrying airline passengers at 215 mph (ref. 8). That aircraft used B–17C wings, tail designs, and supercharged engines.

The period from 1940 through 1945 includes the aircraft developments and immense production expansion of World War II, during which U. S. aircraft industry produced about 300,000 aircraft of all types at a cost of about $45 billion. The "Jet Age" that found its operational beginnings during World War II was based on experimental engine developments in Great Britain and Germany during the 1930's. The British turbojet engine design of Frank Whittle first ran successfully on a testbed in 1937. Modified Whittle designs flew in a Gloster E. 28/29 in 1941 and became operational in the Meteor fighter in 1944. A turbojet engine based on Whittle's designs powered the F–80 Shooting Star fighter for the U. S. Air Force in 1944 (ref. 9).

The helicopter also emerged from experimental status with the production of the Sikorsky R–4B for the Army in 1942 and soon thereafter other manufacturers began producing helicopters of similar configuration, such as the Bell Model 30.

In 1946 the virtual shutdown of military aircraft production was accompanied by a convulsive shift to civil aircraft production that was short-lived and led into the postwar contraction in the industry. From 1950 to 1970, military R&D had major effects on civil aviation that supported civil aircraft production growth even while military aircraft production decreased.

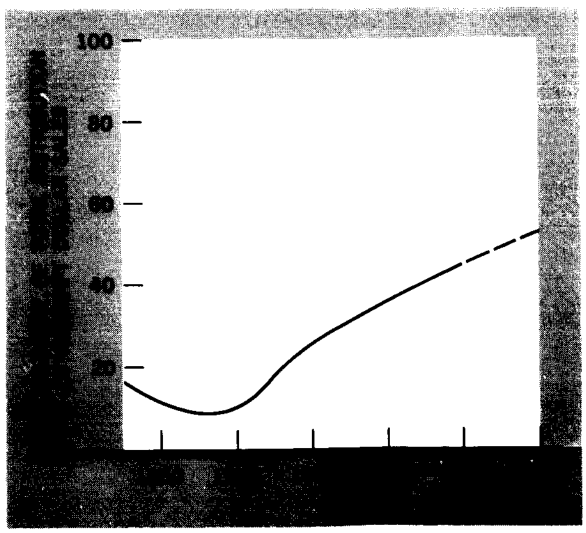


Figure 5.14. Civil aircraft sales as a percentage of total (civil plus Government) sales. Sales of complete aircraft, aircraft engines, propellers, and parts to U.S. Government and others (curve smoothed). *Source: Ref. 6.*

AIRCRAFT SALES

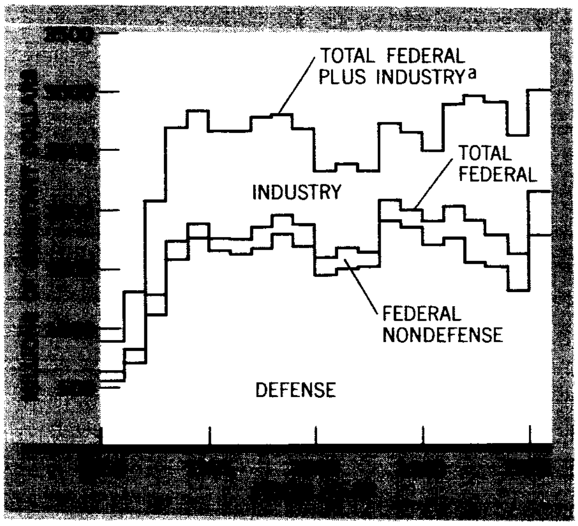
Military aircraft dollar sales still represent the major portion of total U. S. aircraft industry sales, but the civil sector of the market has grown steadily during the past 15 years, as can be seen from Figure 5.14. Although this section of the report provides a focus on the military influences in the aircraft industry, it is also pertinent to keep the defense aspects of commercial aviation in proper perspective. The commercial sector not only provides the Civil Reserve Air Fleet, but there cannot be, in all reality, the necessary military aviation without a strong civil aviation industry capable of quickly responding to increased military production needs.

SIGNIFICANCE OF MILITARY R&D TO CIVIL AVIATION

From today's perspective, it is apparent that military aviation developments have directly influenced the growth of the commercial aviation industry in both its production capabilities and its technology base. The benefits accruing to civil aviation cover nearly every phase of aviation, but are essentially derived from two major influences of military programs: (1) indirect economic support by fiscal expenditures for military programs; and (2) direct economic support of the development of new technology.

Aeronautical R&D Funding

The aeronautical industry is technically oriented, and its growth requires a strong national technological base. The level of funds for research and development is one measure of the activities contributing to this technology base. Federal funds, most of which come from DOD programs, as noted in Figure 5.15, represent about two-thirds of the total annual aeronautical R&D funds (ref. 10). The major portion of the nondefense Federal expenditures supported the aeronautical R&D activities of NASA and DOT.



[a]Data on composite aeronautical R&D funding include estimates for R&D facilities construction, salaries, and allowances for other support costs. Federal contracts for production, as opposed to contracts for research and development, provide about one-half of industry R&D funds as allowable costs under Federal contracts.

Figure 5.15. Aeronautical R&D funding. *Source: Ref. 10.*

Utilization in civil aviation of the aeronautical technology derived from military programs can be extensively illustrated. However, an analysis made by the Joint Study indicates that although advances in aeronautical technology derived from military R&D have potential for substantial application to civil aviation needs, it is the prototype aircraft developments, of all types, that contribute most directly to the industry's overall capability to maintain design and production leadership.

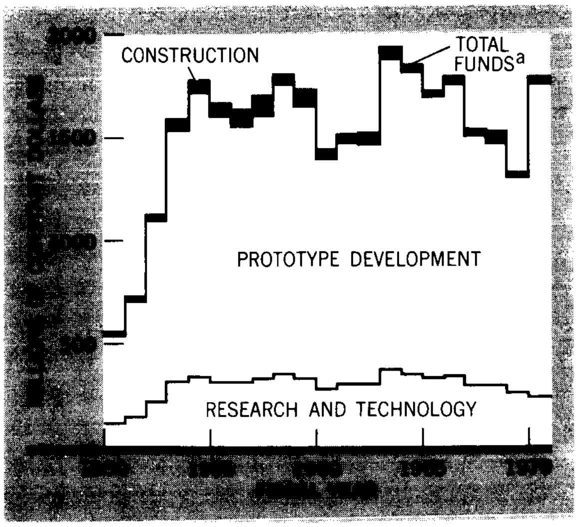
The estimated distribution of DOD funds between prototype aircraft developments and activities in the technical disciplines is shown in Figure 5.16. This figure shows that although (on a constant dollar basis) DOD-sponsored funding for prototype development (the major part of aeronautical R&D funding) declined from the 1963 peak, the trend was reversed in fiscal year 1970 (ref. 10). Military funding for research and technology represents an average of about 30% of the total defense aeronautical R&D funds and, in

recent years, is estimated to represent annual funding levels between $200 and $300 million. An assessment of Air Force projects resulted in an appraisal that as much as 50% of the funds expended toward advancing military technology in the aeronautical disciplines cover areas in advanced technology that are potentially useful to civil aviation.

Figures 5.15 and 5.16 compare broadly derived aeronautical activity data that include manpower cost factors. Therefore, numerical values do not directly reflect the Federal R&D budget figures of the agencies and departments.

Development of New Technology

The development of any aeronautical system depends upon the availability of technology to satisfy its operational demands. The accumulation of a technology data base is a continuing process, and in general, progress is dependent upon the continued utilization of resources. Technology,



[a]Data derived from several sources including selection of those projects considered to be aeronautics oriented from DOD RDT&E "Project List" and estimates for construction obligations for aeronautical R&D facilities. Estimates for salaries and other support costs are also added to the selected projects funding obligations.

Figure 5.16. Distribution of DOD aeronautical R&D funds. *Source: Ref. 10.*

like science, involves commonality in skills and knowledge, which results in a general transfer of technology within industry and Government to meet the varying demands of civil and military aviation. For example, military R&D in support of the XB–70, YF–12 interceptor, and the SR–71 reconnaissance aircraft advanced the technology base in structures, propulsion, and aerodynamics for Mach 3 flight, the civil considerations of which are being further explored in joint Air Force/NASA flight programs utilizing the YF–12 aircraft and also in the civil supersonic transport prototype development program. To provide the technology to meet the needs of a broad spectrum of military aircraft developments and use by the military services, military aeronautical technology programs include such areas as aircraft structures and materials, flight controls and stabilization, aerodynamics, flight mechanics, avionics, communications, navigation, tactical air control and landing aids, safety and survivability, noise, fuels, reliability and maintainability, rotors, propellers, and propulsion. Research in future composite structures for military aircraft offers promise and is being observed closely for direct civil application. Military-sponsored developments in lightweight propeller structures and other advanced propeller designs are contributing to the current industry progress in shrouded prop-fan concepts that could contribute to reducing engine-noise levels of future transport aircraft.

Military research and development in propulsion have led to the development of virtually all of the aviation engines in the United States. Since the propulsion system directly affects aircraft performance and is basic to aircraft designs, a close interaction has always existed between the military and civil sectors for the development of new-engine technology. While engine manufacturers have a substantial financial burden in developing their own specific civil engine models to most effectively meet various civil aircraft characteristics, the basic engine technology has generally been provided through military research. However, engine technology exchange is essentially a complete two-way flow between the military and

civil aviation sectors. For example, the private sector developed the JT3D series turbofan (fanjet) engines to increase the efficiency of designs derived from the J57 military turbojet. The success of these engines then led to the further development of fanjet engines for military applications.

Compressor technology for the very large turbojet engines has its origin in the development of the J93–GE–3 military turbojet for the experimental XB–70A Mach 3 aerodynamic research aircraft. More recently, the engine competition for the Air Force C–5A resulted in the design of the large TF–39 military and JT9D commercial fanjet engines. The General Electric TF–39 was selected for use in the C–5A, while the Pratt and Whitney JT9D commercial engine derived from STF–200 technology is now being used in the Boeing 747 commercial transport. Also, the General Electric CF–6 turbofan engine to be used in the McDonnell Douglas DC–10 commercial transport has been derived from TF–39 gas generator and compressor designs, with the addition of new CF–6 fan and afterbody designs.

Besides the benefits derived from military R&D, other Government-sponsored programs contributing to jet-engine developments include the NASA Quiet Engine Program and the development of the civil GE–4 engine for the SST. It is essential in cost-effective aircraft design to suitably "marry" the best available engine technology to the desired airframe characteristics and performance.

The Role of "New Starts" in Aircraft Developments

For a period beginning in the early 1950's, military aircraft were deemphasized in favor of ballistic missiles and space activities. Despite this deemphasis, the numbers of new starts per year for military aircraft of all types in 1956, and in 1962, almost equalled the 1950 level. Such new starts in aircraft development add to the design expertise and exercise the R&D capabilities of the aircraft industry. Since 1950, the production of civil aircraft increased in two major steps (Fig. 5.13); the 1958 high level of production can be related to the many new DOD aircraft starts in 1950–52 (Fig. 5.17). The doubling in the level of civil aircraft production in 1965 can be related to the high levels of new military aircraft starts in 1956.

Technical Risk Considerations

Technical risk is an important consideration in any development activity. The criteria for the acceptability of risk are generally different for military and civil aviation systems. Economic viability is the dominant factor in development leading to commercial applications, whereas superior combat performance or the threat of technical obsolescence is usually dominant in developments leading to military aircraft weapons systems. Thus, R&D for military equipment tends to provide early operational application in aeronautical weapons systems of advanced propulsion, aerodynamics, structures, and avionics technology. When this occurs, it reduces the technical risks that would otherwise be encountered in applying the same technology to civil systems.

SIMILARITIES AND DIFFERENCES IN REQUIREMENTS

One way to assess the potential for future benefits that may accrue to civil aviation from military R&D is to compare areas having some degree of common interest. It has been recognized that civil and military requirements result in different emphasis on specific aircraft mission characteristics (ref. 11). For example, efforts to provide commercial transport versions of aerial weapons carriers have generally proven unsuccessful over the years (ref. 12). The mission differences have the greatest impact in the area of development, that area in which the body of knowledge is directed primarily at an end product. Thus, there is little possibility that a high performance military airplane designed as an integrated aerial weapons system can be used by civil aviation to any appreciable extent, even

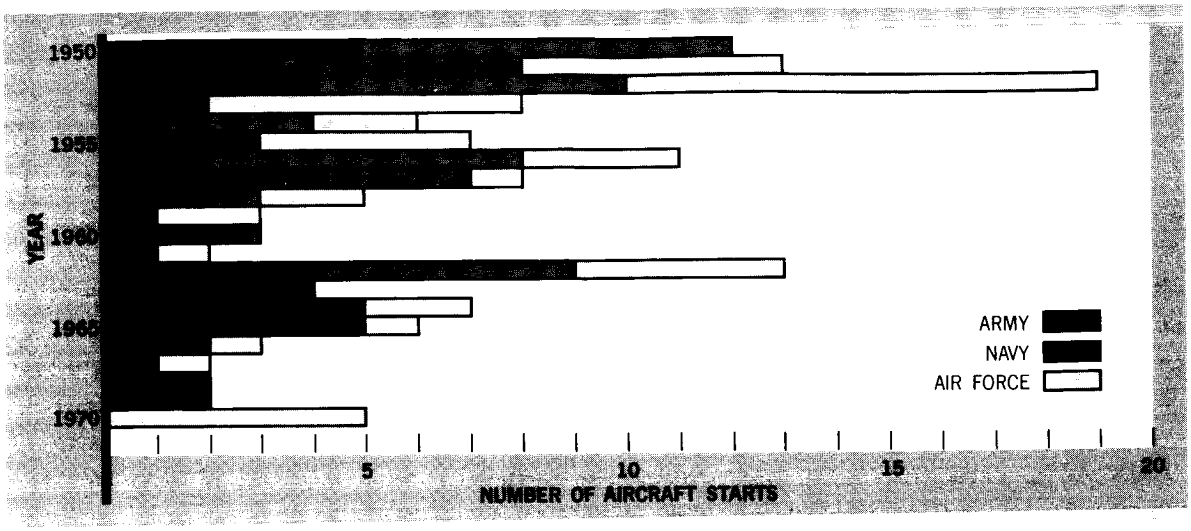


Figure 5.17. Annual number of aircraft development starts by the Department of Defense (including experimental aircraft and fixed- and rotary-wing aircraft of all types).

though substantial benefits may later be derived from advances in aircraft production techniques and subsystem components.

Utility Transportation, Special Activities, and Logistic Support Transports

There is a substantial degree of commonality between military and civil requirements relating to light fixed-wing and rotary-wing aircraft. For rotary-wing aircraft, both civil and military requirements directly relate to the helicopter's ability to take off and land vertically and maneuver in relatively short distances. Therefore, the same vehicle concepts can accomplish special military missions and yet have applicability, with little change in basic design, to civil helicopter operations. Development emphasis for future military applications is expected to stress operational and maintenance simplicity, immediate operational availability, low noise level and economy; these all should enhance the civil usage of the aircraft. For light fixed-wing aircraft, military requirements (for multipurpose utility aircraft for utility transportation, combat-unit support, and other special activities) have been met basically by off-the-shelf procurement of commonly used civil aviation aircraft. Examples of the wide variety of these aircraft, which are produced in both military and civil versions, are listed in Table 5.10.

Also, military and commercial airline requirements for future medium-size STOL/VTOL transport-type aircraft appear to have an appreciable degree of similar characteristics. The capabilities airlines want for future short-haul STOL/VTOL commercial transports are similar to those being considered by the military for future tactical airlift aircraft. Continuing coordination between the airlines, aerospace industry, military, and civil agencies will ensure that wherever practical, benefits in technology and hardware can be applied in both civil and military sectors to meet common requirements. However, considerations of relative priorities and funding constraints within the military and civil sectors indicate that the initiative for early development of a new medium STOL transport aircraft rests with the civil sector.

Logistic Support Cargo Transports

The global military airlift capability provided by such military transports as the four-engine

TABLE 5.10. SELECTED ILLUSTRATIONS OF SIMILAR CIVIL–MILITARY VERSIONS OF ROTARY–WING AND LIGHT FIXED–WING AIRCRAFT

ROTARY-WING AIRCRAFT		
CIVIL MODELS	MILITARY DESIGNATIONS AND MISSIONS	
BELL MODEL 47G SERIES	OH-13 G/T, HTL 6/7	OBSERVATION, TRAINING
BELL MODEL 205A	UH-1H	UTILITY HELICOPTER, "HUEY"
BELL MODEL 206A (JET RANGER)	TH-57A, OH-58A	TRAINING, OBSERVATION
BELL TWIN 212	UH-1N	UTILITY HELICOPTER
BOEING-VERTOL 107-11	CH-46A	CARGO, TRANSPORT HELICOPTER
HUGHES 500	OH-6A	LIGHT OBSERVATION HELICOPTER
HUGHES MODEL 269A	TH-55A	TRAINER
SIKORSKY S-58	CH-34	LIGHT TACTICAL TRANSPORT
SIKORSKY S-61A, S-61R	SH-31A CH-3B	ASW HELICOPTER, TACTICAL TRANSPORT
SIKORSKY S-65C (SEA STALLION)	CH-53C	HEAVY TACTICAL (ASSAULT) TRANSPORT
SIKORSKY S-64E (SKYCRANE)	CH-54B	HEAVY-LIFT CARGO

LIGHT FIXED-WING AIRCRAFT		
CIVIL MODELS	MILITARY DESIGNATIONS AND MISSIONS	
BEECHCRAFT QUEEN AIR	U-21A	UTILITY TRANSPORT
BEECHCRAFT B55 BARON	T-42A	ARMY, INSTRUMENT/TRANSITION TRAINER
CESSNA MODEL 172	T-41A	ARMY, SINGLE-ENGINE TRAINER
BEECHCRAFT QUEEN AIR 65	U-8F	7-PLACE UTILITY TRANSPORT
BEECHCRAFT MODEL 50 TWIN BONANZA	U-8D	6-PLACE COMMAND/LIAISON TRANSPORT
DE HAVILLAND BEAVER	U-6A	6-PLACE, SINGLE-ENGINE, UTILITY
DE HAVILLAND OTTER	U-1A	11-PLACE UTILITY STOL
HELIO COURIER	U-10	6-PLACE STOL UTILITY AIRCRAFT
BEECHCRAFT KING AIR MODEL B90	VC-6A	LIGHT PERSONNEL TRANSPORT
CESSNA MODEL R17 E	T-41B, T-41C T-41D	ARMY, SINGLE-ENGINE TRAINER
CESSNA MODEL 185 SKYWAGON	U-17	LIGHT, SINGLE-ENGINE UTILITY
CESSNA MODEL 310	U-3	LIGHT, TWIN-ENGINE UTILITY
CESSNA MODEL 337	O-2	LIGHT OBSERVATION AIRCRAFT
PIPER PA-23-250 AZTEC D	U-11A	LIGHT, TWIN-ENGINE UTILITY

Douglas C–54 and Lockheed Constellation during World War II significantly expanded concepts for utilization of air transportation. Also combat-support air operations of both sides in the conflict highlighted the need for specialized designs in military transport to handle bulky military equipment and the capability to deliver assault troops and their supplies to forward

combat areas. The large six-engine German Me 323 military transport appeared in Europe with large nose-opening doors and a 10-wheel landing gear mounted in the fuselage (ref. 13). However, the design having only nose doors precluded the air-dropping of large equipment loads to combat troops. Therefore, military transport designs soon appeared with rear cargo doors. The prototype XC–82 Fairchild Packet with clamshell cargo doors in the rear flew in 1944 and was in production for the Air Force by the end of World War II.

Military developments, including the C–141 and the more recent C–5A, have contributed heavily to the technology for cargo aircraft and cargo-handling equipment. Military cargo, however, on the average has a density two or three times that of civil cargo, and military cargo aircraft must accommodate outside loads such as tracked vehicles and helicopters (in contrast to the standardized modular containers for which future civil cargo aircraft will be designed). Because of these and other specialized requirements, the operating costs for military cargo aircraft have been higher than they would be for commercial cargo designs, and commercial carriers have chosen to convert passenger aircraft to cargo service rather than to purchase military cargo aircraft.

Avionics Systems

Both civil and military aircraft are common users of the National Airspace System, and consequently there is a broad base of commonality in requirements for avionics systems. Commercial, military, and civil agencies are participating in cooperative efforts to identify common requirements and standards in such areas as communcations, aircraft identification, altitude reporting, weather-data collection and reporting, and the development of advanced aids in navigation and landing. Such cooperative efforts are exemplified by the activities of Special Committee 117 of the Radio Technical Commission for Aeronautics to define a system concept for a new national precision guidance system for approach and landing (ref. 14).

MILITARY/CIVIL TECHNOLOGY TRANSFER PROCESS

Since many of the same developers of aviation products serve both the civil and military sectors, there is substantial transfer of technology within the aerospace industry. This transfer is of significant value to civil as well as military aviation and, in general, functions effectively. Government agencies involved in aeronautical R&D are coordinated at various administrative and policy levels through interagency agreements and existing Government mechanisms, such as the National Aeronautics and Space Council, the Aeronautics and Astronautics Coordinating Board and its Panels, the NASA Research Advisory Committees, the DOD Advisory Committee on Federal Aviation, and the FAA's Defense Coordination Advisory Committee. These coordination interfaces within the Government among the DOD, NASA, and FAA appear to work reasonably well.

Aeronautical R&D facilities operated by Federal Government agencies and the military services provide mutually supporting capabilities, including exchange of trained personnel, which impact upon both the civil and military sectors. These facilities also provide extensive technical experience in R&D program planning, systems analysis techniques, and program management for the development of complex systems that are of potential benefit to the further development of civil aviation. In this regard, the interface of Government research and development personnel is significant. In the normal day-to-day process of formulating and implementing Government programs involving both the military and civil aviation sectors, these personnel act as catalysts for information and technology transfer through close, personal interaction with manufacturers and technical people across the entire aviation spectrum.

Another important segment of the transfer process is the participation on an *ad hoc* basis of aeronautically oriented professional and management personnel in professional societies and in advisory groups for both Government and industry. Informal groups also exist in certain disciplines and, in fact, contribute significantly to technology transfer at the engineering level. An excellent example of such an informal group is the Interagency Propulsion Panel composed of propulsion engineers from NASA, DOD and its agencies, and FAA. In the past such groups have participated in the assessment of the feasibility of applying a technology to a vehicle concept. Their ability to function in this capacity stemmed from their knowledge of the availability of the new technology that traditionally comes partially from NASA–sponsored aeronautical research, military sponsored R&D, and privately funded supplemental research. In the past this process has been effective in fostering the rapid growth of commercial aviation and the timely development of new aircraft.

CONCLUSIONS AND RECOMMENDATIONS

- Military aviation and its development have been major factors in the growth of civil aviation. Although military R&D programs are aimed toward the solution of military problems, these programs have and will continue to provide major support for civil applications. Civil aviation is interested primarily in the economic aspects of aircraft performance, while the military concentrates more on the prevention of technological obsolescence. Continuing advances in aeronautical technology will make military aircraft obsolete and the military will have to support the development of new types of aircraft. Such new aircraft starts will, as in the past, make it economically feasible to produce new types of civil aircraft.
- There is a common technology base on which aviation manufacturers draw to produce aircraft designed to meet military and civil requirements. Although military oriented research and development has had a significant impact on aviation technology, in certain areas, such as engine efficiency, the advances stem from civil aviation requirements. The switch of the dominant role from military to civil needs has historically been influenced by factors peculiar to specific time periods. Civil aviation now has the dominant role in the development of at least one type of aircraft – a short-haul STOL transport.
- The direct economic influence on the aircraft industry of aircraft sales to the Government, as compared to the private sector, has diminished during the past 15 years because of the more rapid growth experienced in civil aircraft sales. However, sales to the U. S. Government still represent more than half the total dollar sales of the U. S. aircraft industry and are important for the continued strength of that industry.
- The formal Government technology transfer structure is effective. There also is a reasonably effective informal transfer process that operates through the transfer of information from Government to industry and among aeronautical manufacturers, by representatives serving on coordinating groups. These processes should be exploited, whenever it becomes necessary to enhance the technology transfer process, by the mutual exchange within Government of technical personnel.

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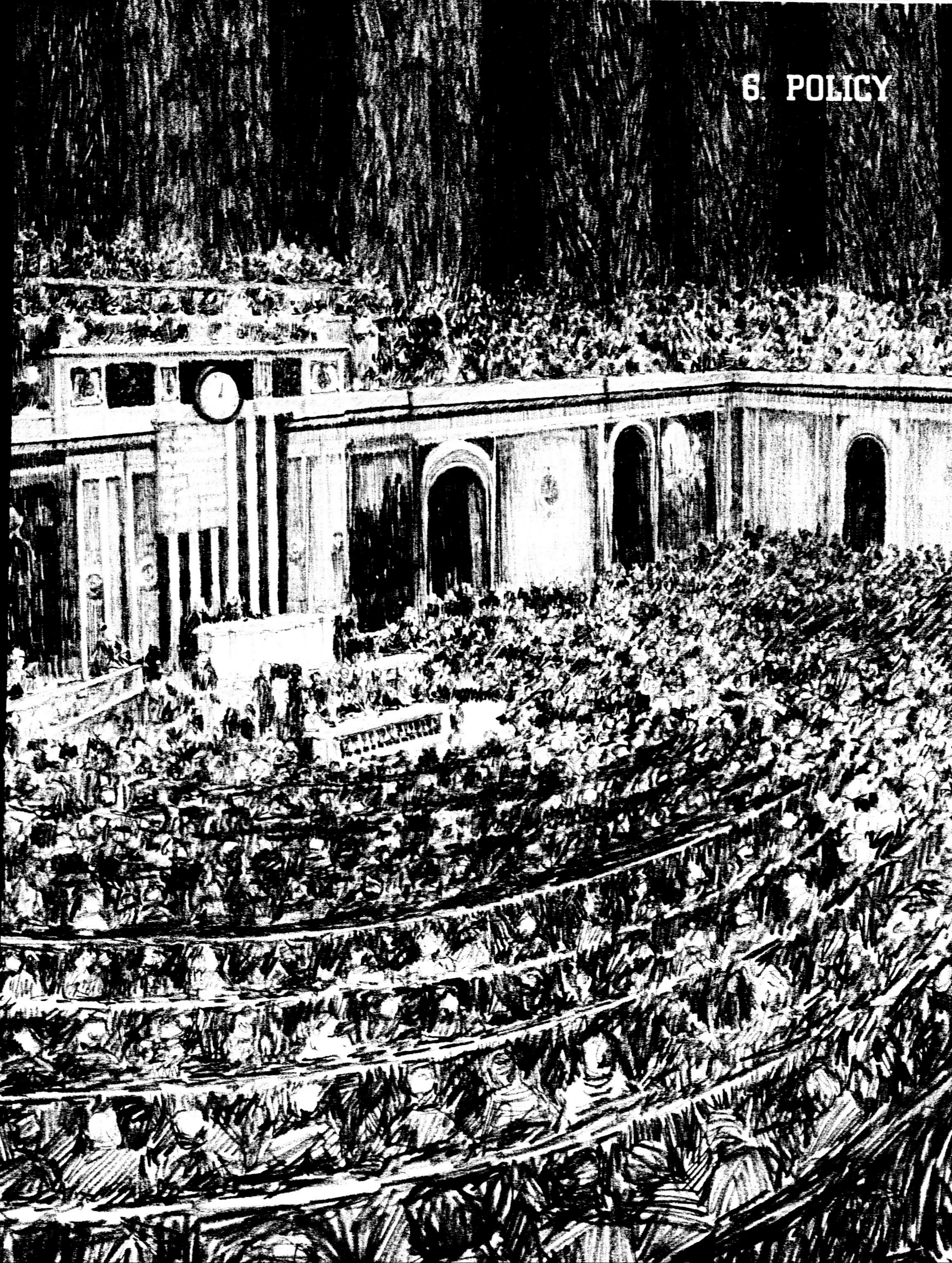
6. POLICY



Policy

INSTITUTIONAL FACTORS

INTRODUCTION

Nontechnical factors that impede the growth of civil aviation and impede the application of the results of research and development have been explored. The specific objectives were: to identify those institutional factors that inhibit the process by which new or improved systems and equipment are developed, implemented, and ultimately operated in response to civil aviation needs; to postulate alternative means (options) of removing these inhibiting constraints; and to catalog the advantages and disadvantages of the selection of any given option as a guide to national policy makers.

This section is based on data collected by a series of more than 175 field interviews of key persons in Government and industry. Interviewees included suppliers, customers of civil aviation R&D, Government officials at all levels, academicians, and other participants in civil aviation. The findings from the interviews have been categorized into a number of factors constraining the process by which the results of research and development are effectively applied to the improvement of civil air transportation. A full report of the findings is contained in reference 1.

CATEGORIES OF CONSTRAINTS AFFECTING THE CIVIL AVIATION R&D PROCESS

Recognized Needs for New Civil Aviation Technology Have Not Been Translated Into Effective Market Demand. Effective market demand involves the readiness of consumers to pay for what they want (their needs), and the willingness of producers to commit resources to satisfy those needs. In civil aviation there is a disparity between established new technology needs and their satisfaction; recognized needs for new aviation technology have not been translated into a clear market to which private enterprise can respond. Without identifiable markets that offer an opportunity for gain commensurate with the risks involved, private industry has rationally avoided committing its resources to meet needs such as the "short-haul market," "the airways market," or the "airport-access market."

The need for improved airport access has not been translated into a visible market with profit potential; as a consequence, private industry has not invested its resources to satisfy this need. The lackluster financial performance of urban mass transit in the country has discouraged potential energizers; costs of a fixed right-of-way system are high, and a lack of market deters producers from undertaking the required R&D. The people who want improved airport access are probably too few to be willing to pay a fare set on a fully cost-reimbursable basis. It seems doubtful that private enterprise will perceive a market for fixed right-of-way access systems to airports – in terms of making a reasonable return on investment – if it must build and operate the system. Fragmentation of responsibility for parts of the total trip and the resultant lack of a systems approach are the major obstacles to progress on the access problem. There is an urgent need for integration of airport access planning with overall mass rapid transit planning. The difficulties affect the movement of air cargo as well as passengers.

A complete STOL system has long been discussed and studied as a possible solution to the country's growing short-haul transportation needs, yet it has not become a reality. No producer of any segment of a STOL system can see a market for his product until he is certain that all other elements of the system will be ready to operate when his is ready. The total costs of the entire system must be reasonable if the fare level is to be within reach of enough air passengers to produce a sufficiently large demand to support profitable service. No responsible participant in the system can estimate confidently what the total costs might be – or more importantly, what his share of the total cost burden might be. In the face of so many uncontrollable and unknown variables, no producer of any segment of a STOL system has been willing to risk investing in it.

In ATC one encounters traffic congestion, travel delays, controller strikes and slowdowns, and an increasing number of near-misses. All clearly indicate that the Nation's air traffic management system is not able to keep up with the demands of civil aviation.

The issue is not, then, whether needs do or do not exist, but why established needs are not being met. Where needs exist, institutional factors have often inhibited the development of an effective response, by preventing the emergence of a firm and visible market for the need, and by limiting the resources of potential suppliers (including the R&D community) to produce, and users to acquire new technology.

The Translation of Recognized Needs Into Effective Market Demand is Inhibited by a Web of Institutional Factors. The principal institutional obstacles of the flow of new technology into civil aviation may be categorized as attitudinal, political, and financial. Clearly, there is a great deal of overlap among these categories. A constraint that is manifested as financial may actually stem from political factors (e.g., specific statutes or regulations). Nevertheless, by categorizing constraints, however imperfectly, the search for options to remove them is facilitated.

In this section, airports and STOL systems are used to illustrate a number of constraints. Certainly, these are not the only problem areas in civil aviation; but because they illustrate the overlap and interrelationship of institutional constraints, and because of their obvious importance, they have been discussed frequently.

- *Attitudinal or social factors* are those based on attitudes that people have adopted, whether for sound reasons or not. Two important attitudinal factors constraining the development and implementation of new technology are a widespread conviction that air transport is important to only a small segment of the population; and that aircraft are noisy, threaten the safety of populated areas, contribute to traffic jams, and create other objectionable conditions. Improvement of the civil aviation system is indeed constrained by lack of a broad constituency.
- *Financial factors.* Certain financial factors are transitory, due to cyclical business patterns, while others are of a more permanent nature. The most important financial factor currently impeding the R&D process is the depressed economic condition of both the aerospace and airline industries. The aerospace industry is less willing and able to commit resources to new technology; the airline industry is less able and willing to acquire and implement new technology. The impact of financial factors within industry may become more deleterious, through managerial deficiencies stemming from individual inadequacies, organizational inefficiencies, or lack of appropriate incentives.
- *Political factors* are those stemming from existing legislation and the regulatory policies that implement existing legislation. These factors also stem from attitudes, of course, but because they are generally codified, in the form of enabling legislation or regulatory policy documents, they are subject to more finite solutions, in that specific legal revisions can be identified as goals for their resolution. Managerial policies and procedures are also included in this category. These practices encompass behavior that is discretionary within existing legal and regulatory parameters, and behavior specified by law and regulation. In many cases, it is difficult to separate managerial behavior into distinct causal groups.

Attitudinal Factors

Aviation's limited political constituency is a major obstacle inhibiting the translation of civil aviation needs into effective market demand. This

reality must be considered in evaluating the likelihood that major new or revised legislative, regulatory, or financial programs are politically feasible. Flying – except for sport or pleasure – is essentially a means of getting somewhere. One travels by air to conduct business, to visit friends or relatives, or to enjoy a vacation. Because whether to travel or not is often a matter of choice and because alternative transportation means exist, it cannot be expected that civil aviation will be valued by society as highly as new homes, for example.

In fact, civil aviation is unpopular with many. The rapid growth of civil aviation has been accompanied by increasing and severe resistance to the expansion of aviation activities. Since the advent of the jets, aircraft movements at many major airports have been increasingly restricted during certain hours of the night. In response to community demands to reduce noise and objectionable factors arising from aircraft operations, other airports have limited their operations to smaller aircraft. At least one community has petitioned the Civil Aeronautics Board to limit further air services, because airport noise was already exceeding acceptable levels.

The role of air transportation in the total national transportation system is not easily perceived. To put the situation into perspective, it is significant that as of 1967, almost half (45%) the U. S. population had not made even a single intercity trip by any mode in the previous year. Of those who had made one or more domestic intercity trips, 88% of the trips were by auto, with air accounting for only 7.5% of all the trips. Clearly then, only a small fraction of the population travels by air. The overwhelming proportion of all domestic intercity travel is by private auto. However, in the domestic intercity common-carrier market (which excludes auto), 64% of the trips and 81% of the passenger miles were by air (ref. 2). Since air carried such a large proportion of the travelers, it is clear that the air mode serves a large cross section of the traveling public. This is confirmed by the fact that in 1967, the median income for all U. S. families and unrelated individuals was $6,889: of those who had taken a trip by any mode, the median was $8,225; of those who had taken a trip by ship, $13,764; of those who had taken an air trip, $11,922; by auto, $8,021; by train, $6,759; and by bus, $5,714. Thus, although the median income of air travelers was significantly higher than the median for the general population, the air traveler's median income of $11,922 shows that air travel is not the province of the wealthy (based on ref. 2).

Although there are many indirect benefits of civil aviation for virtually all of the population, these lack visibility and immediacy. Economic growth, for instance, is directly and indirectly affected by aviation progress; but for the most part, the importance of aviation's contribution is not appreciated by the general public.

The fact that aviation has always been a concern of Government, mainly through a mixed pattern of regulation, subsidy, and support of research, means that many key decisions affecting the fortunes of the industry have been made in the political rather than the market arena. The removal of institutional constraints on aviation, therefore, involves the building of political constituencies. In other words, market demand alone is not sufficient to drive the public-private aviation industry to technologically improved systems. If people generally view air travel as an elitist transport mode, and airports as objectionable neighbors, it will be difficult to generate enthusiasm for projects that involve relieving constraints through institutional change.

The major consequence of aviation's limited political constituency is a constraint on airport development. Although the last decade has witnessed unparalleled growth in airline traffic and major improvements in aircraft, airports have not developed at an equivalent pace – in number or quality. Illustrations include the saturation of Kennedy, La Guardia, Washington National, and O'Hare airports. Over the past 14 years, various

proposals to build a fourth major airport in the New York City area have met with such strong community resistance that an acceptable site has not yet been found, with the result that aircraft activities at New York's airports must be rationed.

Because a disproportionately large number of enplanements occur at a relatively small number of major airports, their failure to develop apace may impede the growth of the total civil aviation system. Indeed, resistance to airports and associated landside development is perceptibly slowing the ability to make use of new technology.

Airports interact in many complex ways with the communities where they are located, but the overall attitude of the community is invariably negative. The reasons – noise, safety, atmospheric pollution, the attraction of unwanted ground traffic – are understandable, but the adverse reactions stimulated in those citizens who live near airports are translated into a virtual paralysis of those agencies charged with planning their expansion or improvement, or with building new ones. Unless airports can be designed that will fit more harmoniously into their surroundings, and an effective pro-air transportation constituency can be developed that will aid in solving such intransigent problems as siting, decision-makers will continue to be frustrated in efforts to keep airport development up with other parts of the system. Resolving the questions of airport feasibility and acceptability will provide industry with considerable guidance concerning the appropriate R&D effort it should place behind STOL, VTOL, or V/STOL systems. By the same token, Government may more safely support demonstration projects, knowing they are politically feasible and likely to trigger further interest of producers and consumers. In short, the stakes here are of paramount importance; if major airports are effectively stopped through either political indecision or a failure to understand which types of airport configurations are acceptable to the people directly affected, the economy, the traveler, and the aviation industry will be the worse.

Financial Factors

Economic conditions in the aerospace and airline industries are inhibiting the translation of new technology needs into effective market demand.

A few key figures tell the story of the growing interdependence of the aerospace and air transport industries, and the dependence of both industries on favorable financial conditions for the flow of new technology between them. In 1969, purchasers other than the U. S. Government accounted for 63% of the backlog of orders for aircraft and related equipment and parts reported by major manufacturers in the aerospace industry. (Comparable figures for other years are 33% for 1959, 25% for 1962, and 46% for 1965, based on ref. 3.) Meanwhile, procurement of aerospace products and services by the U. S. Government is forecast to decrease from $21.4 billion in 1968 to $17.6 billion by 1971, the most protracted and sizable decline since 1948 (ref. 3).

Thus, if it is to maintain current levels of employment and sales, and if it is to grow, the aerospace industry must increasingly look to the air transport industry as a market for new technology. Therefore, the economic well-being of the air transport industry, and its propensity and ability to acquire and implement new technology are now matters of serious concern to the aerospace industry. Currently, both industries are experiencing grave financial difficulties.

Since 1966, the airline industry has been unable to attain a satisfactory return on investment, in accordance with the standards for a fair and reasonable rate of return determined by the Civil Aeronautics Board. In 1969, the U. S. scheduled air carriers reported a net profit of only $53 million on a total investment of $8.6 billion (ref. 4). Two out of every three scheduled carriers reported a net loss for the year. The Air Transport Association estimates that the scheduled airlines will suffer a net loss in 1971, as they did in 1970 (ref. 5).

A consequence of the industry's severe and deepening financial problems is the growing threat to its current reequipment program. Already, cancellations of orders previously placed with airframe and engine manufacturers have been announced. Tenuous financial arrangements for new aircraft are being jeopardized, with the possibility that the airlines will be unable to finance deliveries of aircraft for which orders are still firm.

Are the current financial problems transitory? Or do these problems have long-run implications for the magnitude and viability of the air transport industry as a market for new technology? These are questions of major importance to the air transport and aerospace industries, and to the Nation as a whole.

The aerospace industry, traditionally dependent for much of its sales on the needs of national defense, is notoriously cyclical. In 1940 it was a $370 million industry; by 1944 it had grown to $16 billion, but three years later, with the end of World War II, its sales were down to $1.2 billion. It remained depressed until the Korean War buildup. A slowdown in the late 1950's, a marked increase in activity in the early 1960's, and a brief subsequent slackening were followed by the Vietnam War. Simultaneous with increased military aircraft procurement from 1965 to 1969 came the principal economic impact of the Apollo program and extensive airline purchases of new long-, medium-, and short-haul transports. The manufacturing capacity of both airframe and engine companies became greatly strained, extensive subcontracting with both domestic and foreign sources was resorted to, and industry employment increased substantially.

The manufacturers of civil aircraft and engines have some unique problems. Boeing, Lockheed, and McDonnell Douglas have made investments in the Boeing 747, L–1011, and DC–10, respectively, of approximately $1 billion each. Similarly, United Aircraft and General Electric have very large investments in the JT9D and CF6 engines. In the case of the aircraft manufacturers, these outlays are larger than the total equity of the firms, and will not be recovered in full until 200-300 or more of each type of aircraft have been sold. Near the end of 1970, aircraft orders plus options totaled 197, 178, and 237, respectively. Both the economic situation of the airlines and the existing overcapacity in passenger seats make it questionable whether any of these programs will break even for some time to come, and, as mentioned earlier, there are questions concerning the ability of the airlines to finance the present orders. These programs have required such a commitment of resources by a substantial portion of the aerospace industry that they effectively preclude comparable investments in newer ones until present investments have been recovered.

The general aviation manufacturers face a somewhat different problem. To recover their development costs, although much lower than those of larger airframe manufacturers, an annual increase in sales of around 15% is needed. Sales of twin-engine and turbine-powered aircraft are very closely correlated with corporate investment in new facilities and equipment, and those of smaller general aviation aircraft with personal disposable income. Thus, general aviation sales are highly dependent on the perceived state of the general economy. The current depressed economic situation has not only arrested the growth of general aviation aircraft manufacturers but reversed it.

Neither the large nor the small airframe companies currently are in a position to continue the more-or-less orderly progression of new model development that has characterized the industry for over a decade. This would not necessarily be critical except that, because of a similar slowdown in new military programs, there are few other projects in most companies to which unoccupied development engineers may be transferred. The industry faces a situation in which its vital development base may erode through disuse.

Traditionally, the airline industry has not been the initiator of detailed technical requirements for new commercial aircraft. The aircraft

manufacturers have maintained a detailed familiarity with airline growth and operations, initiating proposals for new aircraft models when they perceived the time to be ripe. The airlines, on the other hand, have made skillful use of the highly competitive nature of the airframe and engine industries to obtain aircraft more closely suited to their particular requirements and to encourage price cutting.

Except for the recession of 1960–1961, the years following the introduction of the Boeing 707, the Douglas DC–8, and their successors were profitable for the airlines. These aircraft were much more productive than their predecessors, and, stimulated by a buoyant economy, passenger volume increased greatly. By 1965 the combination of growing demand, air terminal congestion, and high expectations for air cargo led the three major airframe companies to propose new high-capacity aircraft. Through 1966 and 1967 the airlines ordered enough 747's, L–1011's, and DC–10's to launch all three programs. Competitive pressures forced many air carriers into reluctantly ordering this new generation of equipment before they had adequately digested the 707, DC–8, 727, DC–9, and 737.

The airbus market, which could probably support one manufacturer in comfort, is being shared between Lockheed and McDonnell Douglas, both of whom have large sums at risk and are far short of a break-even level of sales. Furthermore, there is considerable overlap in range and productivity among the wide-bodied jets on many routes, and the availability of the tri-jets at appreciably lower prices ($16 million versus $23 million) has contributed to a slowdown of 747 sales. To summarize the situation, too many manufacturers are extensively committed to aircraft for which the airlines are not really ready, either financially or in terms of capacity. The suppliers and the users appear to have overstimulated each other, and the result is disruption and financial strain for both parties.

An examination of the earnings experience of the airline industry during the 25 years since World War II adds further support to the view that periods of depressed earnings encountered by the industry are not solely due to cyclical downturns in the economy. During the economic downturn of 1949, the industry's rate of return was higher than it was in the two previous years. In the 1953–1954 economic downturn, industry rates of return were among the highest levels of the postwar period. However, starting with the downturn of 1957–1958, the industry seems to have reached a state of maturity that no longer enabled it to remain immune from the ills of the general economy. In 1958, 1961, and 1970, traffic growth came to a virtual halt and profits slipped markedly.

The cycling of airline earnings also appears to be related to industry's reequipment programs, which usually increase existing passenger and cargo capacity significantly beyond demand. The low rates of return experienced between 1947 and 1949 coincide with reequipment with pressurized propeller aircraft. The low rates of return experienced in 1957 to 1963 and 1970 coincide with reequipment with the final pressurized propeller aircraft series, introduction of turboprop and turbojet aircraft, and introduction of the wide-body 747.

The incentive to overequip comes from competitive desires to be first in the marketplace with the most of the best aircraft, and to longstanding beliefs in the industry that capacity and frequency of service stimulate traffic. Statistics have generally confirmed that this is indeed the case. This compelling line of reasoning has recently been constrained by the financial problems of the industry. Air carrier equipment purchasing power was limited by credit standing. However, in successive waves of financing, the airlines have progressed from highly conservative bank credit sources, to insurance companies, and now to the leasing company. With each wave, the industry has moved to less restrictive sources of capital and reached new levels of overcapacity.

Reequipment brings not only overcapacity, but also a set of secondary effects on airline operation, all of them costly and some difficult to

foresee. These include induced needs for additional training of flight and ground personnel on new aircraft, additional or new ground facilities, special aircraft-related equipment of all kinds, and the customary "bugs" in new and highly complex aircraft. The net effect is a sharp rise in operating costs resulting in depressed earnings.

The coincidence of reequipment and depressed earnings is a chronic problem that affects the implementation of new technology and is impairing both the economic health of the air transport industry and its standing as a market for aerospace products and services. The manifestations of this problem directly affect the aerospace industry in two ways. There is a natural incompatibility between the need of the aircraft manufacturer to achieve and maintain an economic rate of production on a large run of aircraft and the ability of the airlines to absorb new equipment, particularly now when equipment comes in increments of 350 seats and $23 million per aircraft. Progressive rounds of reequipment have usually resulted not only in overcapacity for the airlines but an increase in the capacity of the aircraft manufacturing industry. Second, the economic perturbations set up by the reequipment cycle within the airline industry tend to make it a less stable and receptive market for the aircraft manufacturing industry.

It can be correctly argued that these risks are inherent to the free enterprise system, and so should be accepted by the participants. However, it is also true that civil aviation is a national asset, one of the largest employers in the country, one of our principal technical resources, and a vital factor in national defense and balance of payments. When the scale of resources required to develop a commercial aircraft or engine approaches that needed today, the results of miscalculation or unforeseeable events may be catastrophic. Disruptive instabilities in this industry and in its civil market must be alleviated or mitigated in the national interest.

Political Factors

The full potential for technological development is being constrained under the present regulatory system.

Economic regulation of the transportation industries in the United States results from many years of experience in balancing the interests of private firms with the public interest. Although statutory authority for transport regulation derives from the powers granted to the Congress under the Constitution, the economic basis for regulation is rooted in the concept of natural monopoly.

Nowhere in the development of regulation are there specific instructions directing regulators to take the effects of technology into account. Such considerations are, however, implicit in a section of the Federal Aviation Act of 1958 that directs the Civil Aeronautics Board to consider the encouragement and development of an air transport system properly adapted to the future needs of commerce as being in the public interest, and in accordance with the public convenience and necessity (ref. 6).

One of the problems is that regulation can work to the detriment of technological innovation. Entry into, and exit from, markets, as well as price competition, are closely controlled. The benefits conferred on the public by the regulatory process are not free of cost, however. Among the costs of this system are the partial loss of technical and managerial innovation that might be expected to result from a struggle for competitive advantage if transport firms were subject only to free market forces.

The requirement that the Board certify for service applicants who are "fit, willing, and able to perform . . . transportation properly," provided that such proposed transportation "is required by the public convenience and necessity" places an enormous burden of proof on

applicants for entry. It serves to assure that only the most conservative proposals receive serious consideration by the Board. Yet the history of technological innovation in the United States amply demonstrates that the successful introduction of new developments in the market occurs not because market feasibility had been proved, but because someone – either through foresight or luck – had a strong conviction that the idea would work. The concept that the marketplace should be the final judge of value is basic to our economic system, and has served to stimulate technical innovation. One might question whether such innovations as xerography, computers, or even the airplane itself would have been developed and sold if the final decision depended on an adjudicatory agency finding an applicant fit, willing, and able, and in consonance with public convenience and necessity.

Another constraint imposed by economic regulation is system sluggishness – that is, the inordinately long time it takes the regulatory system to rule that an air carrier will be permitted to respond to a need even when the technology to do so is available or can be made available. The CAB's Northeast Corridor STOL Investigation has been under way for two years; the Phase I report was issued in September 1970. It is conservatively estimated that the Phase II hearings may take at least another two years. The CAB has concluded that such a system is needed, yet as many as five years probably will have passed before significant action is taken to meet this need. The following excerpt from the Phase I hearing states the problem and provides a good summary of many institutional constraints that are holding up STOL system development:

> that a properly implemented metroflight system will be responsive to (the) major public need and . . . such a system is both technically and economically feasible . . . . We recognize that the establishment of a comprehensive metroflight service . . . will not be free of difficulty, since its chief components – suitable aircraft, landing sites, and navigation technology – are not yet fully developed. All these elements, however, are clearly within the ambit of existing technology, and could be available within a relatively short space of time with the active commitment of the aircraft manufacturers and governmental bodies involved. A chief obstacle to progress toward metroflight has been the cycle of inaction that has affected the participants in its development; local authorities lack incentive to develop landing sites in the absence of some assurance that appropriate VTOL/STOL aircraft will be available to use them, manufacturers are reluctant to begin active production to aircraft until they have sufficient orders, and carriers are unwilling to order equipment unless they can look forward to suitable landing sites. It is our hope that the Board's action in authorizing metroflight operations will break this impasse and serve as a catalyst for more active implementation of a viable VTOL/STOL system (ref. 7).

The slow development of short-haul markets, air-cargo traffic, and resolution of the 12,500-pound weight restriction inhibiting development of commuter-market aircraft are examples of the deleterious effects of regulatory lags.

THE PRESENT CAPABILITY OF THE FEDERAL GOVERNMENT TO DEAL WITH THE PROBLEMS

The nature of the civil aviation problem is such that only the Federal Government is in a position to provide the leadership and direction necessary to break the institutional impasses and inadequacies that stand in the way of realizing the full R&D potential. The Government cannot solve all the problems, but it can solve some and at least establish a viable framework for the ultimate

resolution of others. What then are the constraints within the Federal Government that are inhibiting it from assuming a more forceful and effective leadership position on civil aviation research and development?

- *The ability of the Federal Government to formulate a comprehensive civil aviation policy is severely limited, given the nature of the problem and the institutional structure in which it must operate.*

Traditionally, transportation planning occurred on an *ad hoc* basis, or when considered comprehensively, by mode. Canals, roads, sea-going vessels, autos, and finally airplanes spurred a fragmented Government response that ultimately produced the present modal administrations within the Department of Transportation. The current array of regulatory agencies (Federal Maritime Commission, Interstate Commerce Commission, Civil Aeronautics Board) was also produced by this long process. The evolution of committees, bureaus, and agencies to deal with each transport mode was determined by economic and political muscle wielded at various times by each mode, and by the Government's special needs for expertise to contend with a particular modal requirement. The question of allocating scarce resources among competing needs was never so important as it is today – the traditional approach resembled a requirements approach, and the problem of measuring "policy trade-offs" did not exist.

The problems in achieving a national transportation policy constrain the formulation of civil aviation R&D policy, and ultimately the marshaling of Federal attention and action to address the problems. The technical means are available or, with sufficient R&D funding, can be made available. Civil aviation R&D, however, is competing with other significant national needs, generally deemed to have higher priority, for limited national resources. The question is where civil aviation needs stand in national priorities. The Federal Government has not been able to resolve this question.

- *The full potential for technological development is constrained by fragmentation of the decision-making process at all levels of Government, including Federal.*

The fragmented nature of the decision-making process is one of the most serious obstacles to attaining technology's full potential in aviation. Perhaps nowhere in civil aviation is this more apparent than in the cluster of problems surrounding the Nation's airport system. This complex and interrelated system requires extensive, coordinated, and informed decision-making; in addition to this, the airport planning and executing function must respond to mounting resistance over questions of siting, landside planning, access, and finance. The fact that lead time from conception to completion is so long for airports – 10 years or more – further complicates the problem. Renewed emphasis on the urban environment has raised the stakes, but the ability to site new facilities has not grown.

Although the need for higher capacity airports has long been recognized, very little research is being done to achieve technical solutions to the challenge. The airport, which serves as the key interface for all segments of the air transport system, has no one group or owner with the motivation or authority to perform the R&D necessary for improvements. For example, airports are concerned with traffic development and operations; FAA jurisdiction and funding authority cease when air safety is no longer a factor. Airlines have not been willing to extend their R&D concerns beyond their legitimate franchise areas; they have focused very little R&D attention on baggage-handling, ticketing, etc., probably because they are not convinced that more people would fly if air travel delays and irritations were significantly reduced. As yet there is no recognizable market for improved airport-access systems. These are the province of local govenmental agencies and have low priority when compared to

other pressing urban problems. This fragmentation of interests and authority through many local, state, and national jurisdictions, combined with diverse interests of the private sector has resulted in a near-impasse that obstructs the flow of technology into airport development.

The need for a better short-haul system is generally accepted. Airborne and ground delays in short-haul flights have frequently nullified the benefits of speedy jet equipment. Today, the block-to-block time of a Boeing 727 flying from New York to Washington has not improved appreciably from what it was a decade ago using DC–6B's.

Given the historic unprofitability of short-haul routes, the lack of success in developing successful STOL is perhaps not surprising. It seems unlikely that aircraft development itself can solve the problem. Any new short-haul aircraft that must operate in the same air traffic control, runway, and airport environments as long-haul aircraft will continue to be subject to most of the same delays experienced by the current generation of short-haul aircraft. A new short-haul system is needed that can function compatibly with the long-haul system.

Institutional fragmentation has blocked any substantive achievements toward this goal. The development of an operational STOL system must involve the integrated efforts of a large number of private organizations and government agencies at the Federal, state, and local levels. Two major components of a STOL system are the responsibility of the Government – the air traffic control system and the airport, or STOLport. The customers must look to the Government (CAB) to delineate the circumstances under which STOL aircraft could operate, while the manufacturer must look to the FAA for certification of the aircraft and engines. Finally, both the private sector and the Federal Government must look to state and local governments for the approval and development of STOLports. A STOL system has not been instituted because no single participant in the process needed to create the entire system has the ability to proceed independently of the others.

The foregoing discussion suggests that R&D in the physical sciences alone is not sufficient to bring about the desired improvements in civil aviation.

CLASSES OF OPTIONS AVAILABLE TO THE FEDERAL GOVERNMENT TO DEAL MORE EFFECTIVELY WITH THE CIVIL AVIATION R&D PROCESS

There are a number of options open to the Federal Government to improve the civil aviation R&D process. None of these is easy to implement, since all depend upon support from the Administration, the Congress, and ultimately the public. On balance, however, the options seem feasible within the context of current national values and priorities. Moreover, the options discussed here are thought to be the most important ones stemming from this part of the Study.

- *Civil aviation research and development should be redefined to include both physical and social sciences and the necessary steps should be taken to organize and staff R&D activities to reflect this new approach.*

Specifically, the Federal Government should augment its physical science staff at its various research and development agencies and centers with experts in such areas as economics, finance, government, market research, and sociology. These people should be encouraged to interact on a day-to-day basis with technical staff members so that a multidisciplinary attack can be launched on the problems of civil aviation. Thus, problems in both the physical and social sciences, and confusion about the direction research should take can be flagged early in the development process – not after it might be discovered, too late, that a solution was being offered for a nonexistent problem, that because of institutional constraints a new

technology could not be applied, or that work was not under way on a problem possibly solvable by technology. The current organizational and conceptual separation of physical and social sciences R&D must cease if the Nation is to avoid falling into many of the pitfalls of the past.

The potential benefits of such an approach are suggested by Department of Defense experience. Within the Office of the Secretary, the Director of Defense Research and Engineering has a staff organization that is mission-oriented rather than geared to technical disciplines (e.g., tactical warfare or strategic and space systems rather than electronics, missiles, or aircraft). In this office, the technological disciplines have been blended, and operational personnel are included in each mission office. These latter personnel represent in effect, the social sciences. Although the analogy between defense and transportation R&D is a weak one, the concept of combining technical with nontechnical personnel signals a recognition by DOD of the benefits that can accrue from such an arrangement.

In the air transport R&D field, where products must be responsive to public needs and values, social and physical science considerations should be explored simultaneously. Ignoring or deferring the latter has inevitably resulted, and will continue to result, in either the rejection of technologies that have been developed or the failure to develop needed technologies.

- *The Federal Government should consider the commitment of substantial resources to Market Demonstration Programs. These provide a unique opportunity to overcome institutional inertia and test promising solutions to civil aviation problems (needs), without committing resources to a full-blown system that might not succeed.*

Demonstration programs afford an opportunity to suspend temporarily many of the institutional constraints that have inhibited the introduction of new technology into civil aviation. In some cases they may provide the only opening for the application of technology to meet the Nation's legitimate air transport needs.

Demonstrations should be employed in a far more extensive and imaginative manner than they have in the past. A few very important technical (proof-of-concept) and market demonstrations have been attempted in commercial aviation. Subsidization of helicopter, domestic trunk, international, and local service carriers are examples. Without such assistance, the U. S. air transport system as we know it today – the strongest in the free world – might not have come into existence.

Demonstration projects are an important means of mustering resources to solve special problems when normal institutional processes inadvertently conspire to prevent the application of new technology. The introduction of radically new air transport systems like STOL, for example, presents so many uncertainties that no single participant seems capable of taking the lead to produce an operating system. It is under precisely such circumstances that demonstration programs can be used to help prove or disprove plausible, but untested concepts.

In the initial CAB decision on the use of VTOL and STOL aircraft in the Northeast Corridor, the Examiner noted that, not only was the "existence of a carrier fit, willing and able to initiate the service . . . obviously an essential ingredient," but also that "the prospect of the carrier's economic success is germane to the question whether it will undertake the operation. If it were shown that there is no chance of financial success, due to lack of patronage, or excessive costs, this would raise serious doubts regarding the institution of the service" (ref. 8).

The groundwork is thus set for a demonstration program rather than the much riskier venture of establishing a full-blown STOL service. However, a STOL demonstration program, unless properly planned and implemented, could do more

harm to the ultimate development of STOL than no demonstration at all. The operation of a Twin Otter or a Breguet 941 in the current air traffic control system, using an existing instrument approach system, might only demonstrate that people would rather fly in a DC–9, which can do the same thing with greater passenger comfort. Similarly, a demonstration using too few vehicles and providing poor service because of infrequent schedules might yield wholly erroneous information on market acceptance.

The costs of demonstration programs, if properly implemented, can be far less than costs required to establish a full-blown system. A valid STOL demonstration program might cost several hundreds of millions of dollars for the aircraft and engine-design competition and resulting demonstration equipment, the new ATC system for routes selected, a steep-gradient approach system, and the STOLport. The Federal Government would probably have to finance a major part of such a system. Commencing today, the system would probably not be ready for demonstration until the mid- or late 1970's.

Because of the institutional constraints on the development and introduction of a STOL system, a demonstration program of this magnitude is probably the only way the "iron ring" can be broken. Deciding whether or not the costs of such a demonstration would be justified in terms of future benefits to the Nation is a separate matter. It seems clear, however, that if a STOL system is in the national interest, this is the direction the Federal Government must take, since it alone has the financial resources and authority to initiate such a project.

Demonstration programs of a more modest nature are also needed to provide a better understanding of how the market and the airlines are likely to respond to various innovations in service, fares, and competition. For example, very little is known about what might happen if airline fares were increased significantly in the short-haul market. Would traffic drop off drastically, slightly, or not at all? Should airline fares be based on the cost of operating any given route segment rather than on the aggregate costs of all routes? With fares based on route-segment costs, would aircraft be priced out of the short-haul market, thus firmly establishing boundaries on the "natural markets" of aircraft versus, say, high-speed trains?

A demonstration program could also address the question of allowing unrestrained competition on high-density routes, thereby providing some test-tube answers to the relationship between regulation and the marketplace.

- *Airports could enlarge their political constituencies by exploring multiple use of land.*

There is considerable evidence that the Nation's largest urbanized regions will not readily endorse further airport development. Unless ways can be found to make airports "better neighbors." CTOL and STOL airport development in and around the largest hubs appears blocked. Research and development in the areas of engine-noise suppression and pollution control may alleviate the problems, but it cannot do the whole job. New CTOL airports, which require vast acreages and accessibility from principal collection points within a region, will preempt land at the urban periphery. Community opposition to airport siting and expansion indicates that imaginative ways must be sought to translate airport-related land acquisitions into multiple-use projects.

There are several options that could aline disparate interests behind airport development. Urban areas face many decisions relating to land-intensive functions that are carried out on or near the urban periphery. For instance, reservoirs, land reclamation projects, estuarine preservation, recreational areas, and public open space offer opportunity for acquiring large land areas for multiple uses. While not all land-use activities are compatible with airport development, a flexible strategy of advance acquisition of land, funded partly or wholly under the Airport and Airway Trust Fund could gain support for airports from sectors which are not hostile.

Conservationists and open-space enthusiasts, for instance, are frustrated over the lack of funds available for state and local acquisition of park land, wild river-basin areas, and other natural land areas that are accessible to our expanding urban populations. If land is not set aside for meritorious public purposes, continuing urban sprawl will preempt present open space for private use.

A political constituency could be developed for airports by means of an airport land-acquisition program – if two conditions are met. Funds must be diverted for acquisitions years ahead of actual need; consideration must be given to acquisition of multiple sites near urban areas. Groups interested in conserving land for recreational or other land intensive activities could aline with airport proponents to prevent scarce open spaces from being developed for low-density residential, commercial, or industrial uses. Political support here is predicated on the belief that environmentalists will endorse a constructive program that guarantees them at least some of their land needs now. Multiple-site acquisition in advance of airport needs would permit community leaders to avoid committing any particular site for airport development.

When airport development is required, the Federal Government could sell superfluous sites to state and local governmental bodies, perhaps at a price equal to the original acquisition cost, plus an accrued interest equivalent. This approach assures that funds would flow back into the Airport and Airway Trust Fund and other Federal sources, and that the price would be attractive to other governmental units. The Federal Government would actually be involved in a landbanking operation that temporarily transfers airport funds to real estate holdings, at no cost to airways users. In the long term, the real economic cost would also be minimal, because the option does not sacrifice or utilize community resources; rather, it provides for transfer of ownership of existing resources, most of which have few alternative uses (e.g., swamps, wetlands, and agricultural land).

It is important to point out that the problem of interagency coordination can be substantially alleviated through the development of what are, in effect, interagency objectives and programs. A present constraint on coordination is the lack of mutual programs among agencies. Multiple-use projects could serve as the rallying point for further positive coordination.

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POLICY ISSUES

A systematic review of the current and projected positions of U. S. civil air transportation reveals that past Government policies of financial support, guidance, and protection of the aviation complex were originally appropriate but have now produced an environment that constrains R&D innovation and adaptation to changing socioeconomic conditions. Some of the problems suggesting that policy has not kept pace with changing conditions are:

- Short-haul air transport has almost invariably been unprofitable.
- Door-to-door travel time has improved very little since about 1960; it is even forecast to get worse instead of better.
- Terminal air traffic capacity has been exceeded at four airports, with 20 to 30 overcapacity airports forecast by 1980.
- Existing airports, hemmed in by urban growth at their boundaries, cannot expand to meet demand.
- Employment and earnings in the industry have dropped sharply; this is due to aircraft overcapacity and high costs of introducing new aircraft – aggravated by a slowdown in the general economy.
- STOL systems appear to have great potential in the short-haul market, but no comprehensive implementation plans have been undertaken.

A common characteristic of these problems is that they transcend technology alone. Nontechnological – institutional factors including economic regulation, legal structures, multiple political jurisdictions, changing social priorities, and complex interactions among multiple Federal agencies are seriously affecting the climate for technological innovations. Some of the symptoms, while basically physical in nature (for example, airside and landside congestion at airports), in reality are largely products of institutional factors.

Although air transportation and the functions it fulfills have changed radically in just the last decade, regulation and policy – the "ground rules" – have not kept pace. Policies once appropriate to protection of an embryonic industry are no longer applicable to an industry that is one of the largest employers and also one of the largest exporters in the Nation. Appropriate civil aviation policy is essential to the utilization of future R&D because policy can create an environment conducive to new market development or can completely stifle it; policy can make efficiency the motivating factor (thus encouraging R&D) or it can encourage a preoccupation with protective practices; policy can give impetus to initiate R&D to attain self-sufficiency or it can foster dependency.

Four policy issues have been selected for special analysis because they are important to the continued growth of civil aviation in the decades ahead. These issues are:

- U. S. leadership in civil aviation
- Demonstration programs
- Removal of regulatory and legal constraints on integration of transportation systems
- Airport location and landside integration with the airside system

U. S. LEADERSHIP IN CIVIL AVIATION

The Issue

How and to what extent should the U. S. Government act to ensure that American aircraft, aviation-equipment manufacturers, and scheduled and nonscheduled airlines achieve an adequate share of current world equipment sales and traffic, and in addition assure that they are in a strong position to move into new major markets opened by technological advancement?

The President has recently reaffirmed the U. S. policy of maintaining world leadership in

civil aviation. His statement called for Federal support of new aircraft development when such development was vital to maintaining our future position in world markets (ref. 1). With the policy stated, the U. S. leadership issue becomes one of examining alternate courses of action open to the Government, and determining the crucial points where action will produce the greatest effect.

U. S. leadership in civil aviation can be defined as the achievement and holding of a recognized first-rank position in any one or a combination of a large number of measures of civil aviation progress. The measures differ depending on the role of the interested parties.

To manufacturers, leadership means that, given a free choice, prospective customers will purchase U. S. products more often than not. U. S. industry will thus lead in sales to both foreign and domestic customers for most items (and particularly for high-cost items).

To air carriers, leadership means that U. S. carriers, having the opportunity to compete on an equal footing in all significant air travel markets in the world, will gain a larger share of the total market for passengers and cargo than any of their competitor foreign-flag carriers.

To air travelers and shippers, it means that the service provided to them by U. S. carriers is second to none in terms of safety, reliability, economy, convenience, character, and quality of service.

To the general public, U. S. leadership in civil aviation means a number of things perceived as accruing to the Nation as a whole. These are:

- A favorable balance of trade in aviation products
- A high contribution to domestic employment and to GNP from civil aviation
- A strong and balanced transportation system
- Use by other nations of U. S. air traffic control, navigation, and safety concepts, as well as U. S. aircraft and associated equipment
- Maintenance of a strong civil aviation industry as an element of national security
- "Showing the flag" by having many – and excellent – U. S. products in evidence in other countries

The interests above are of concern to a multiplicity of Government agencies (Commerce, State, Treasury, Transportation, Labor, Civil Aeronautics Board, and Defense).

This discussion of U. S. leadership will be focused on the sales of aircraft and aviation-equipment manufacturers to both domestic and foreign buyers, and on the market share achieved by U. S. carriers. Preeminence in each of these two areas is considered to be the dominant factor in maintaining overall U. S. leadership in civil aviation.

Current Leadership Status

The United States clearly enjoys a world leadership position in civil aviation today as it has for the past several decades. An examination of the factors influencing leadership indicates the extent to which leadership has been attained:

- 76% of the free-world commercial aircraft are U.S.–manufactured (ref. 2).
- 63% of the aircraft operated by free-world foreign airlines are U. S.–manufactured (ref. 3).
- U.S. airlines operate 41% of the free-world airplanes (ref. 2).
- The seven largest airlines in the free world are U. S. carriers (as measured by combined passenger and cargo ton-miles flown in 1969) (ref. 3).
- In 1969, more than 57% of the free-world scheduled passenger-miles (domestic and international) were flown by U. S. carriers (ref. 4).

- More than one-third of the total value of U. S. civil aviation products are exported (ref. 5).
- The U. S. exports almost three times the number of general aviation aircraft as the rest of the free world.
- The dollar value of U. S. exports of parts and engines is more than half the value of U. S. exports of complete aircraft (refs. 6, 7).
- Although aerospace employment in Western Europe is about one-third of U. S. aerospace employment, Western Europe aerospace sales are only 15% of U. S. aerospace sales (ref. 8).
- The net contribution of civil aviation to the balance of trade in 1969 was $1.5 billion; this is about equal to the *total* positive U. S. balance of trade in 1969 (refs. 5,9).
- Civilian aerospace employment is a strong national asset (in 1968, it amounted to 830,000, counting both direct and induced employment).

Factors Contributing to U. S. Leadership

United States leadership in civil aviation did not arise suddenly or result from a deliberate plan. Rather, it was the result of a series of events and circumstances spanning at least the past 40 years. A few of the significant factors are (refs. 10, 11):

- Charles Lindbergh's flight in 1927, which provided an emotional stimulus that caught the imagination of the country.
- The rapid growth in the 1930's of United, American, Pan American, Trans World, and Eastern airlines, which became models for airlines in the rest of the world.
- The U S. need for long-range strategic aircraft in World War II, which laid the foundation for the development of long-haul transcontinental and intercontinental air systems.
- The geography of the United States, with large population centers 1,000 miles or more apart, often separated by physical barriers that handicapped surface transport and made long-distance travel a highly desirable goal.
- The Douglas DC–2, which in 1934 opened the eyes of the world to the new quality standard of U. S. transport aircraft (which, before 1934, were surpassed by the aircraft of France, Germany, and Great Britain).
- Worldwide use of 10,000 C–47's (DC–3's) during World War II, which brought the attention of the world to the capabilities of U. S. transport aircraft.
- The production of about 300,000 aircraft during the 1940–45 period, which resulted in the establishment of a gigantic industry, with a few large companies and a high degree of automation, capable of producing the types and quantities of aircraft required for the civilian sector.
- Military funding of airframe and engine research and aircraft production during the war and postwar years, which resulted in a large reservoir of technology adaptable to civil aviation.
- Following World War II, most countries, occupied with rebuilding their economy, were unable to concentrate on aviation manufacturing for 5 to 10 years. As a result, they made large purchases of U. S. aircraft.
- U. S. manufacturers developed the ability to move quickly into fields often originated by others.

Many of the leadership factors previously listed resulted from large-scale production of aircraft for military use, coupled with large-scale production of civil aerospace items within the same industry. Together, they have provided skilled management, production workers, and facilities (with the "learning curve" largely paid

for by the Government), the scale of operations and incentive to increase productivity per employee, and a size and strength to undertake the long and expensive development and tooling-up period that precedes the sale of new large aircraft.

The superiority of U. S.–manufactured aircraft is not due to a technological edge alone, but to the entire marketing package – technology, sales skills, adaptability to customer needs, financing, production techniques, reliability, family of products, and after-sales service. The combination of these factors has permitted levels of production and sales, and quality of servicing of vehicles not as yet been matched by foreign competition. This leadership position resulted from a set of historical circumstances that, for the most part, were not initiated by the civil aviation industry. Whether this position of world leadership is maintained, strengthened, or lessened will depend on the policies followed by industry and Government.

Changing Quality of Foreign Competition

At the moment, the U. K. and U.S.S.R. are the only countries with technical capabilities and comprehensive aerospace industries comparable to those of the United States. However, Japan, France, West Germany, Sweden, the Netherlands, and Canada are not far behind. Although the United States spends four times as much for space and defense R&D as do Western Europe, Japan, and Canada combined, these countries are spending more for *civil aviation* R&D at the present time than the United States. Currently, foreign countries *equal* the United States with such developments as the VC–10 and all-weather landing equipment, and *lead* the United States in such areas as supersonic aircraft, STOL aircraft, lift engines, cold-weather operating equipment, and fiber composites. While this does not mean U. S. leadership is immediately threatened, continued aggressive efforts on the part of these countries must be expected to make competition for world markets more difficult in the future.

Consortia. The potential expansion of the European Economic Community (with the inclusion of the U. K. in the Common Market) will make the European "equivalent domestic market" as large as that in the United States. The aerospace companies of several nations are already working together and in some cases combining. Consequently, Western Europe could be a much more potent competitor than in the past (particularly in the short-haul market, since most flights on the continent are short-haul).

Foreign Customer Financing. As a step toward enabling American companies to compete with the low financing rates offered by foreign companies helped by Government underwriting or nationalized banks, the U. S. Government, through the Export-Import Bank, has authorized or guaranteed loans to assist in financing civil aerospace exports valued at more than $3.5 billion in the past 10 years. The statutory limitation on the lending authority of the Export-Import Bank is $13.5 billion. More than $10 billion of this is committed (refs. 12, 13). Without this source of funds, the marketing position of U. S. aviation products abroad would be weakened.

Subcontract Work. The large amount of work being subcontracted to foreign countries by U. S. manufacturers helps the sales of U. S. products abroad by virtue of the purchasing power gained and the association of the foreign country with the development of a product.

Business Slowdown. A factor favoring foreign competition today is that Western Europe is not having the economic slowdown that prevails in the United States.

Industry Financial Situation. U. S. airlines as well as aerospace manufacturers are experiencing a serious recession. This is partly due to the fact that the introduction of a major change in aircraft has produced a temporary overcapacity. It is further accentuated by inflation, cutbacks in space, and the high cost of delays arising from terminal

congestion. As a consequence, the aircraft manufacturers have cut back employment by 20% in 1970 (ref. 14). With sales dropping, R&D is cut back – bringing a potential adverse effect on future sales. The manufacturers' annual interest on long-term debt was $186 million in 1969 and climbing, further compounding the problem (ref. 5).

Airline overcapacity and business cutbacks have resulted in the worst earnings loss in air carrier history. Adding to the problems, airline wages increased 64% in 10 years and rose another 11% in 1970 (ref. 15). Terminal area delays alone cost the U. S. airlines $158 million in 1969, an amount about equal to their expected net losses in 1970 (ref. 16). If all these factors continue, in the long term, the basic health of the industry could be undermined.

Aircraft Development. Today, it requires an investment of about $1 billion by an aircraft manufacturer to develop a new aircraft of the size and complexity of the 747, the DC–10, or the L–1011 – a sum which is several times the company's net worth. No appreciable financial return accrues to the manufacturer for 5 to 10 years after he begins such a program. With more than 20,000 suppliers and vendors involved in a major aircraft development, delay – or failure – to deliver by any key supplier or vendor can cause an added financial strain on the aircraft manufacturer. On the positive side, the skills developed in recent years in the management of very complex programs (e.g., Apollo) puts the United States in a better position than other countries to control and direct such comprehensive operations.

R&D. The importance of R&D to sales is apparent when it is recognized that 52% of 1973 aerospace sales will be derived from new products not in existence in 1969 (ref. 17). Military-funded R&D has supported civil aviation to a considerable extent either directly as in the case of engines, or indirectly from military-oriented R&D programs that provided technology usable by civil designers. A number of specific civil needs, however, will not be satisfied by military R&D in the future, and additional specific and concentrated efforts will be required by the civil sector. Such things as noise and air-pollution research, better low-speed flight characteristics, reduction of wake turbulence, better crosswind landing capabilities, anticollision systems, fire hazard reduction, improved ATC, and all-weather operations affect capacity, economics, safety, and environment. The manufacturers (or countries) that provide economically acceptable solutions to these problems, especially in noise reduction, can gain competitively, particularly if they also have a strong marketing capability.

Technology. Today, no country has the leadership in basic technology, since technical knowledge is fairly universal. This is due in large part to the activities of technical societies and international organizations, and to modern communications. Technical advantage now depends principally on maintaining technological *lead time*. The strength of the U. S. aviation industry lies mainly in its ability to develop and implement new technology generated here or abroad. For example, although the jet engine was developed in the U. K., the inability of British manufacturers to fully develop and apply the advance to transport aircraft produced in large numbers has cost them heavily. The U. S. aircraft industry, on the other hand, has not experienced constraints in development and production.

Examination of the factors that appear to have brought leadership to the United States and future trends in those factors indicates that there is a link between our strong domestic market and such leadership. Consequently, it is believed that any actions taken to build a strong domestic market will strengthen U. S. leadership as well. For example, if the United States produced quiet engines or developed an economically sound short-haul system, the probability is high that other countries would also find the products involved attractive.

Leadership Indicators

The factors that have contributed to U. S. leadership in civil aviation are many. These factors, when quantified and compared over time with the same factors for other nations of the world, can provide a valuable perspective by helping to define and measure the somewhat imprecise concept of leadership and provide a possible basis for formulating policy. The indicators are analogous to the economic indicators that have become accepted as elements in the measurement of the health and activity of the economy – and that are carefully studied in the process of formulating any new national economic policy.

The following indicators are presented as measures of the major facets of leadership in civil aviation. The list of indicators is tentative; it clearly needs further development and refinement. Lack of data on many of the indicators for nations other than the United States prevents comparison among civil aviation industries of the world. Even when comparable data are available caution must be exercised in drawing conclusions or establishing cause-and-effect relationships until greater experience is gained with the indicators.

Military Indicators. Military R&D and procurement has had a significant influence on the health of the U. S. civil aviation industry. As the aerospace industry's single largest customer, the Department of Defense has heavily supported the development of production skills for military products the industry has applied to its production of civil products. This spinoff has contributed to a production efficiency for the U. S. aircraft industry unequaled by any other country. Annual sales to the Department of Defense, over the past decade, when measured in constant dollars,[1] have been fairly level (Table 6.1). This indicates that there has been as yet no substantial downward trend in military procurement of aerospace products and supports the conclusion that the U. S. aircraft industry currently enjoys the benefits of continued Department of Defense support for its products, little different from what it enjoyed a decade ago.

TABLE 6.1. AEROSPACE SALES TO THE DEPARTMENT OF DEFENSE (BILLIONS)

CATEGORY	1961	1963	1965	1967	1969
CURRENT DOLLARS	13.9	14.2	11.4	15.9	15.8
CONSTANT DOLLARS	16.2	16.2	12.5	16.5	15.1

Source: Ref. 5.

[1] All constant-dollar figures are based on 1968.

Although the ratio of total aerospace sales to civil sales has dropped significantly (Table 6.2), examination of the data making up the ratio shows that civil aviation sales have been gaining at a much faster rate than total aerospace sales, a healthy sign for civil aviation. If military sales should decrease, however, the allowance of R&D costs as part of the overhead expenses of military contracts will also decrease. In difficult financial times, the industry may not be able or willing to invest as heavily in R&D when a smaller percentage of such costs can be charged to government contracts. Funding of research and technology may be reduced in order to meet development and production commitments. Thus the future technological strength of the industry may suffer.

TABLE 6.2. SALES IN THE U. S. AEROSPACE INDUSTRY

SALES AND SALES RATIO	1961	1963	1965	1967	1968
TOTAL U.S. AEROSPACE SALES: CIVIL SALES	8.6	12.2	6.7	5.4	4.7
U.S. AEROSPACE SALES, CURRENT DOLLARS, BILLIONS	16.4	18.3	18.7	24.7	24.2
CIVIL AVIATION SALES, CURRENT DOLLARS, BILLIONS	1.9	1.5	2.8	4.6	5.1

Source: Ref. 5.

R&D Indicators. R&D expenditures indicate to some extent the technological strength and

ability to move into new markets, although it must be recognized that the United States has also been very successful in marketing technology developed in other nations. Important indicators include those shown in Table 6.3.

Total aerospace R&D as a percent of all aerospace sales is an important indicator, since much of the military R&D is transferable to civil aviation. This ratio has remained nearly constant over the past decade.

Both civil aviation R&D and civil aircraft sales have increased to approximately 2.7 times their 1961 levels and, as a result, the ratio of civil aviation R&D to aircraft sales has remained stable over the decade.

Independent R&D (IR&D) makes up the bulk of civil aviation R&D and is composed of private R&D plus funds supplied indirectly by the Government as an allowable cost on Government procurements. IR&D increased by 40% in constant dollars between 1961 and 1969, but civil aerospace sales increased by 120% during the same period. Although private R&D is increasing its portion of IR&D, private R&D as a percent of civil aerospace sales has fallen off over 30% (refs. 5, 6, 7). (IR&D has limited usefulness as an indicator, since no comparable indicator exists for other nations of the world.)

In the past, propulsion advances have often led to the development of new vehicles. To the extent that this remains the case, the propulsion R&D indicator can provide an early glimpse of future market strength. Propulsion R&D fell off about 25% between 1961 and 1969 when measured in constant dollars (refs. 6, 7). Before any

TABLE 6.3. THE RELATIONSHIP BETWEEN R&D AND SALES IN THE U.S. AEROSPACE INDUSTRY

R&D AND SALES	1961	1963	1965	1967	1969
TOTAL AEROSPACE R&D: TOTAL AEROSPACE SALES	0.13	0.13	0.13	0.12	0.12
TOTAL AEROSPACE R&D, CURRENT DOLLARS, BILLIONS	2.1	2.4	2.4	2.9	2.8
TOTAL AEROSPACE SALES, CURRENT DOLLARS, BILLIONS	16.4	18.3	18.7	24.7	24.2
CIVIL AVIATION R&D (DIRECT): CIVIL AIRCRAFT SALES	0.17	0.23	0.14	0.17	0.16
R&D, CURRENT DOLLARS, MILLIONS (DIRECT)	315	348	401	772	835
CIVIL AIRCRAFT SALES, CURRENT DOLLARS, MILLIONS	1,876	1,485	2,816	4,632	5,064
TOTAL INDUSTRY R&D (REIMBURSED PLUS PRIVATE R&D)					
CURRENT DOLLARS, MILLIONS	599	577	657	1,017	1,066
CONSTANT DOLLARS, MILLIONS	701	658	723	1,057	1,010
PRIVATE R&D					
CURRENT DOLLARS, MILLIONS	306	284	353	565	609
CONSTANT DOLLARS, MILLIONS	358	324	389	587	582
PRIVATE R&D: CIVIL AIRCRAFT SALES	0.16	0.19	0.13	0.12	0.12
PROPULSION R&D					
CURRENT DOLLARS, MILLIONS	342	245	291	334	347
CONSTANT DOLLARS, MILLIONS	400	379	320	347	331

Source: Refs. 5, 6, 7.

conclusions can be drawn, however, a careful breakout of propulsion R&D and comparable data for other nations are needed. An R&D breakout by objectives such as noise and air-pollution reduction and by funding source, particularly private funding, are necessary further refinements.

Production Indicators. A recognized strength of the U. S. aviation industry has been its greater output per labor dollar and its greater output per employee compared to the rest of the world. Maintaining this edge is essential to the future success of the industry.

The value added-per-labor-dollar indicator (Table 6.4) shows the United States with a slim margin over some other industrial areas of the world in 1966. Whether the margin is still favorable to the United States today is not certain since wages have increased by 17%, from an hourly wage of $3.30 in 1966 to $3.87 in 1969, but increases in productivity have not kept pace (ref. 5).

TABLE 6.4. COMPARISON OF PRODUCTION INDICATORS, UNITED STATES, EUROPEAN ECONOMIC COMMUNITY, AND GREAT BRITAIN (1966)

INDEX	EUROPEAN ECONOMIC COMMUNITY	GREAT BRITAIN	UNITED STATES
INDEX OF VALUE ADDED PER LABOR DOLLAR	1.0	1.0	1.1
INDEX OF VALUE ADDED PER EMPLOYEE	1.0	0.68	1.99
INDEX OF LABOR COST PER EMPLOYEE	1.0	0.68	1.79

VALUE ADDED (U.S.)	1961	1963	1965	1967
VALUE ADDED/EMPLOYEE				
CURRENT DOLLARS	6,016	5,716	7,070	8,367
CONSTANT DOLLARS	7,036	6,517	7,795	8,697

Source: Refs. 7, 18.

Another significant indicator is the length of a production run for a particular aircraft type. Large production runs, resulting from the factors that have raised the United States to its position of leadership, have benefited from, and contributed to, favorable cost-and-marketing-indicator comparisons, as discussed in the next section. Orders, including deliveries and options on record as of October 1970, are shown in Table 6.5 for selected aircraft comparisons.

Marketing Indicators. U. S. aviation products have sold well throughout the world. Statistics show the dramatic increase in world market share enjoyed by U. S. manufacturers over the past decade. The ratio of U. S.–manufactured planes on order to foreign-manufactured planes on order was 1.4:1 in 1960, 3.4:1 in 1965, and 5.0:1 in 1969 (ref. 20). The large U. S. domestic market for aircraft has guaranteed to airframe and engine manufacturers production runs sufficiently long to allow them to offset costly initial cash outlays for development. (It should be noted, however, that the full advantage of large production runs is not realized because the manufacturer must tailor transport airplanes to each customer's desires – see section on "Financial Considerations.") The large domestic market for civil and military aircraft has also permitted U. S. manufacturers to accumulate sufficient statistical data on the performance of their products to modify them so as to achieve even greater economy and efficiency. It has not been sufficient for a country to develop an element of advanced technology first:

TABLE 6.5. CURRENT ORDERS FOR SELECTED AIRCRAFT

AIRCRAFT TYPE	ORDERS PLUS OPTIONS
TWIN-ENGINE JETS	
DC-9	654
BAC-111	200
THREE-ENGINE JETS	
B-727	851
HS TRIDENT	82

Source: Ref. 19.

although the U. K. was the first to develop the turbojet, it was U. S. manufacturers with their guarantee of an enormous domestic market – and thereby assurance of large production runs – who capitalized on the turbojet market. Orders for U. S. turbojets versus foreign turbojets were in the ratio of 675 to 82 in December 1969. In December 1960, the ratio was 290 to 130 (ref. 20).

More striking is the comparison of the dollar values of the orders, indicating increasing sales volumes for the U. S. aerospace industry's civil products. The ratio of value of U. S.–manufactured planes on order to the value of foreign-manufactured planes on order was 1.8:1 in 1961, 6.4:1 in 1963, and 19.7:1 in 1969 (based on ref. 20).

That the excellence in American civil aviation products is recognized by foreign airlines as well as our own is evidenced by the $1.9 billion in U. S. exports of civil aircraft, engines, and parts reported for 1969. The balance of trade for civil aviation products is dominated by exports: U. S. imports of civil aviation products amounted to $0.2 billion for 1969, giving a net trade balance for the aerospace industry of $1.7 billion (Table 6.6).

TABLE 6.6. U.S. BALANCE OF TRADE (BILLIONS)

BALANCE OF TRADE	1961	1963	1965	1967	1969
CURRENT DOLLARS	0.76	0.71	0.75	1.25	1.77
CONSTANT DOLLARS	0.89	0.81	0.83	1.30	1.76

Source: Refs. 5, 9.

Comparing the U. S. trade balance for all aircraft, engines, and parts (including military) with that of a close competitor, the U. S. balance in 1969 was more than 60 times that of the U. K. (ref. 21). One obvious reason for U. S. aircraft selling well abroad relative to foreign aircraft is their profitability, as indicated by direct operating cost (DOC) over the lifetime of the vehicle. A comparison of DOC's for two sets of competitive aircraft, one U. S. and the other foreign, is shown in Table 6.7.

TABLE 6.7. DIRECT OPERATING COST COMPARISON (PLANNING ESTIMATE)

AIRCRAFT TYPE	INDEX OF DIRECT OPERATING COST ON A SEAT-MILE BASIS
TWO-ENGINE	
DC-9 (U.S.)	100
BAC-111 (U.K.)	106
THREE-ENGINE	
B-727 (U.S.)	101
HS TRIDENT (U.K.)	103

Not only are the marketing indicators favorable to the U. S. but the trend seems to indicate improvement with time. The total free-world balance of trade on aviation products has eroded over the past four years while the U. S. position has improved by an almost equal amount. The percentage point spread on DOC's between U. S. and similar foreign aircraft can amount to several hundred thousand dollars per airplane over its lifetime. Multiplied by an entire fleet, the cost differential can amount to millions of dollars – a very important factor when profits are traditionally a very small percent of sales.

Financing Indicators. The ability to offer attractive financing often determines the consummation of a sale. The Export-Import Bank has been an important factor in stimulating sales of U.S. aircraft abroad.

The indicators (Table 6.8) show a substantial increase in involvement on the part of the Export-Import Bank. As its total lending authority of $13.5 billion is approached (at present $10 billion is committed), this source of aviation funding should be watched closely to assure that its effectiveness is not lost (refs. 12, 13).

TABLE 6.8. FINANCING OF U. S. CIVIL AIRCRAFT EXPORTS BY THE EXPORT–IMPORT BANK

INDICATOR	1960-64	1965-69
PERCENT RECEIVING FINANCIAL ASSISTANCE	11	40
CIVIL AIRCRAFT EXPORTS, MILLIONS OF DOLLARS	4,372	7,447
EXPORTS RECEIVING FINANCIAL ASSISTANCE, MILLION OF DOLLARS	490	2,982

Source: Ref. 12.

Air Carrier Indicators. Besides serving as obvious monitors of the health of the air carrier industry, these indicators (Table 6.9), particularly overall (ton-mile) load factors, can serve as advance indicators of the need for aviation products.

The air carrier indicators show an uneven picture. U. S. air carriers are increasing their share of the market, but profits are falling and overcapacity is appearing throughout the entire industry. Non–U. S. airline profits have followed the pattern of U. S. profits, but at a lower level. Value added per U. S. air carrier employee is growing – although it may have fallen in 1970.

Considering all of the indicators, the most significant indicators appear to be:

- Ratio of total aerospace sales to civil aircraft sales
- Ratio of total aerospace R&D to total aerospace sales
- Value added per labor dollar
- Length of production run
- Ratio of value of U. S.–manufactured aircraft on order to value of foreign-manufactured aircraft on order

Of the five indicators, none seems at present to indicate leadership problems for the U. S. civil aircraft industry, although no comparable data for other nations were found for the first two indicators. The ratio of total U. S. aerospace sales to U. S. civil aircraft sales, although falling, seems to indicate that civil sales are growing at a much faster rate than military sales. However, a decline in military procurement will also cause a reduction in the allowance for IR&D, which may deter industry from investing in as much research and technology. The ratio of total U. S. aerospace

TABLE 6.9. AIR CARRIER INDICATORS

INDICATOR	1961	1963	1965	1967	1969
PERCENT U.S. REVENUE PASSENGER-MILES (DOMESTIC PLUS INTERNATIONAL)	54.8	55.2	55.7	58.2	57.6
PERCENT U.S. REVENUE TON-MILES (DOMESTIC AND INTERNATIONAL)	53.7	54.7	58.9	64.0	64.1
VALUE ADDED/U.S. EMPLOYEE,					
CURRENT DOLLARS	9,950	11,510	12,710	13,570	
CONSTANT DOLLARS	11,710	13,100	14,000	14,100	
PROFIT AS A PERCENT OF OPERATING REVENUES					
U.S. AIRLINES	−2.0	5.8	12.1	9.5	
NON-U.S. AIRLINES	−2.1	3.2	6.9	5.0	
U.S. AIRLINES: NON-U.S. AIRLINES	1.0	1.8	1.8	1.9	
OVERALL (TON-MILE) LOAD FACTOR					
U.S. AIRLINES	NA	49.2	50.3	50.9	46.7
ALL ICAO AIRLINES	51.7	50.6	51.7	50.7	47.7

Source: Refs. 4, 6, 15, 22, 23.

R&D to total U. S. aerospace sales appears to be holding constant. Value added per labor dollar, although favorable in 1966, is of limited usefulness without data for additional countries and without data for other years to permit establishing a trend over time. The length of production run is very favorable for those aircraft-type comparisons that were included. Finally, the ratio of the value of U. S.–manufactured planes on order to the value of foreign-manufactured planes on order indicates a strongly improving U. S. position.

For the air carrier industry, all of the indicators noted are considered significant. U. S. air carriers appear to be in a strong position *relative to non–U. S. air carriers.* Falling profits and overcapacity, as evidenced by falling load factors, appear to be plaguing the entire industry. As previously noted, load factor in particular can serve as an advance indicator of the need for aviation products.

In summary, the overall position of the U. S. civil aviation industry is very favorable. The substantial momentum of the industry can be expected to sustain this position over the next few years, although individual companies will neither contribute nor share equally. Such momentum, however, should not be cause for complacency. Once the momentum is lost, it is likely to be significantly more difficult to regain than to have retained it through timely minor actions.

Conclusions and Recommendations

- In the past, substantial Government support of both military and civil aviation has been the key factor bringing worldwide leadership in civil aviation to the U. S. This leadership position came about largely as a by-product of building a strong national defense and a healthy domestic market.
- Most indicators reflect increasing strength. One indicator – the level of propulsion R&D funding – is decreasing and warrants more detailed analysis. While growing overcapacity in the air carrier industry portends problems for the airlines as well as the aerospace industry, the U. S. leadership position does not appear to be currently threatened thereby.
- Analysis of the indicators shows that the U. S. position in civil aviation is still strong and no specific Government action is suggested at this time to improve that position. These indicators have not yet been tested and should not serve as substitutes for other analyses that, for example, might suggest changes in the Export-Import Bank, or more liberal policies relating to allowable charges against military contracts. Actions suggested elsewhere in this report, designed to improve the domestic market, should find equal acceptance in foreign markets and will help maintain and enhance our position of worldwide leadership.
- The demonstrated importance of civil aviation in world affairs (e.g., international prestige, balance of trade, and maintenance of defense superiority) suggests the desirability of pursuing U. S. leadership in aviation matters in a more active manner.
- If the United States is to consciously pursue a course of strengthening the U. S. position in civil aviation in the world community, it is necessary to develop a set of leadership indicators to quantitatively assess its progress and to measure the reaction to specific courses the Government elects to take. It is therefore recommended that the Department of Commerce accept the charter to measure, test, and refine these suggested indicators on a continuous basis, so that this complex issue may be better understood.

DEMONSTRATION PROGRAMS

Issue

To what extent should the U. S. Government conduct or support demonstration programs in the field of civil aviation?

Definition

Demonstration programs are needed to prove out new systems and technologies, to assess market potentials, or to remove major institutional constraints temporarily. Demonstration programs are experiments designed to embrace new concepts, procedures, regulations, or the blending of new technologies into existing systems. These programs should collect information and required data in a real-world environment involving the ultimate users of the system. Two types of demonstrations have been considered. "Operational demonstrations" would be designed to test the effects of the introduction of new elements on the operations of present systems (e.g., testing the effect of a STOL vehicle on the ATC system). "Market demonstrations" would be designed to test market reaction and examine the effect of new elements or other changes on such factors as equipment, fares, routes, and service. In either case, the demonstrations should be carefully designed to test key variables and collect required data so that the information necessary for the guidance of R&D programs can be obtained. Market or regulatory experiments can be as important to the R&D process as operational demonstrations. With accurate data on price, frequency, and service elasticities available, the manufacturer is in a better position to evaluate trade-offs and requirements for new systems. In addition, a properly designed demonstration program can provide the basis for definitive cost/benefit analyses.

Importance of Demonstrations

Significant changes in living patterns and land use during the past decade have made re-evaluation of existing transport systems both an economic and social necessity. Generally, the evolution of new travel patterns and requirements have outstripped the systems that originally stimulated growth. Although, in the past, technical developments of air vehicles were the principal motivation behind this rapid growth, "systems" improvements will play an increasingly important role in the future. The uncertainties of how to proceed to an optimal system, the number of different groups required to effect change, and the involvement of Government in many phases of air transportation suggest the need for some form of Federal involvement in demonstration programs if an orderly and responsive development of the air transportation system is to be achieved in the decades ahead.

Some of the present conditions and trends that support the need for demonstrations are:

- Systems complexity -- no one private corporation has significant control over the many diverse elements of the total system. The complexity of the system acts as a deterrent to the development of some system improvements such as providing adequate service to the short-haul market.
- Congestion – The FAA estimates that, in 1969, delays due to congestion cost the airlines \$158 million and 22 million man-hours (ref. 24). Noise, slow airport processing, inadequate ground transportation to and from the airport, lack of suitable land acquisition programs for new airports, airspace management, and control and regulations all contribute to the problem, and need to be considered together when selecting solutions.
- Political processes – opposition to airport expansion or construction of new airports will force airports farther from the areas they serve. This will result in lessened interest by the city in the airport, coupled with an increased burden on ground transportation systems. With these realities, experiments are needed to

analyze optimization of location versus access versus environment versus door-to-door travel time.

- Ground access – one airport handling 50–100 million passengers per year could require as many as 50 lanes of freeway to handle the crowds. New techniques of handling movement of people need examining.
- Nature of passengers – A greater percentage of all travel in the future will be for pleasure (by 1985, pleasure travel is expected to represent 70% of the total travel market). There will thus be increased interest in reduced fares and possibly less interest in travel time and quality and quantity of service. Market experiments are needed to match capability with the changing demand.
- Regulation – Currently, fare changes and route awards are argued before the CAB largely on the basis of price elasticity and market demand. Under these circumstances, the proceedings are more time-consuming and costly than would be a contingency award or a demonstration on a limited basis in the market. With the latter approach, conjecture would be replaced by facts.

Transportation Demonstration Programs

The Government has not had extensive experience in air demonstration programs. The 1958 Acts creating NASA and FAA contain provisions (refs. 25, 26) allowing demonstration programs, but very few have been conducted and even in those few there usually has been no relationship to the economics of normal operations.

In some ways, the CAB subsidy programs represent the best examples of demonstration programs. Up to 1951, $200 million were given the domestic trunks; through 1954, $300 million to international carriers; through 1970, $1.1 billion to local service carriers (including carriers in Hawaii and Alaska) and $51 million to helicopter carriers between 1954 and 1966 (ref. 27). These investments in both domestic and international carriers have successfully demonstrated the attractiveness of air travel to the public. To date, the subsidies to local service and helicopter carriers have not culminated as successful demonstrations. Nor have experiments with all-cargo carriers or nonscheduled charter carriers proved conclusively successful. Additional value would have been received from these "experiments" (particularly helicopter and local service) if there had been more emphasis on the gathering of data (especially market elasticity data), through experiments involving orderly variations in price, frequency, and service choices. Market or regulatory experiments could be very important to the R&D process. With accurate data on elasticity of the market with price, frequency, and service available, the manufacturer and the airline would be in much better positions to evaluate trade-offs and requirements for new systems.

The airlines themselves have undertaken demonstrations. Eastern Airlines and American Airlines STOL demonstrations, using Breguet aircraft, represented essentially technical demonstrations, without marketplace effects. Market effects were considered, however, in the development of suburban passenger terminals in New York by several airlines and in the fostering by Allegheny Airlines and other local service carriers of scheduled third-level commuter passenger service.

While these examples show that there has been some limited use of demonstrations in the past, the growing complexity of the market, the great financial risk associated with the development of new aircraft, and the need to select new systems from balanced systems analyses rather than from piecemeal technological improvements all point to an increasing need for demonstrations in the future.

Government Involvement

Government involvement is already provided for by the Department of Transportation Act

(ref. 28) that states "... the Department of Transportation should assure the *coordinated* effective administration of the transportation program of the Federal Government ... *encourage cooperation* of Federal, state and local government carriers, labor and other interested parties ... provide *general leadership* in the identification and solution of transportation problems ...." The Secretary, then, under existing legislation, can clearly undertake demonstration projects in any areas of transportation where they may be needed. The need for such DOT initiatives are dependent upon many considerations, including the ability of private industry to perform a required demonstration without Government participation.

Based on past performance, private industry can be expected to make evolutionary improvements to the civil aviation system, and both the airlines and aircraft manufacturers may be expected to work together towards this end when the proper economic incentives are present. Under certain conditions, however, private industry may not be able to take the necessary action, in which case, if any progress is to be made, Government involvement will be needed. Some of these conditions are:

- No element of private industry can perform the task because it lacks sufficient jurisdiction and because of institutional barriers or other factors. In these cases, industry cannot control enough of the environment to proceed.
- Industry is not the prime mover as is the case in most airport development programs.
- Private industry will not proceed for financial reasons – either the initial investment is too great or the profits lie too far in the future. In addition, a private firm will be reluctant to engage in an expensive demonstration when the benefits cannot be restricted to itself, but would accrue equally to its competitors.

In these cases, Government involvement is justified if the following conditions are met:

- The service being demonstrated is in the public interest.
- The service potentially has broad application.
- The demonstration is designed to produce results pertinent to a total transport system.
- The service has the potential of operating profitably (or with a reasonable initial subsidy, if it is in the public interest).
- The demonstration is responsive to both market and political processes.
- All parties involved accept their appropriate share of responsibilities for financing and for operations.

If these conditions are met, the Federal Government may assume any number of roles – planner, coordinator, regulator, funder, impartial evaluator, or operator. Table 6.10 shows some of the advantages and disadvantages associated with the various roles.

The approach selected should be compatible with the criteria being used to assess the advisability of Government-assisted demonstration programs in other industries. These more general criteria include:

- Industry must share the risk.
- No industry member may be placed in a favored position.
- The forces of the marketplace must be recognized.
- Competition must be maintained.

These criteria can be satisfied by civil aviation demonstrations if:

- Demonstrations are jointly funded by Government and industry.
- Industry forms joint ventures to work with Government.

- Where appropriate, both manufacturers and airlines participate in joint ventures.
- If possible, more than one industry participates and competes in the program.

Each demonstration proposal will require a different mix of participation, but emphasis should be given to increasing the responsibility of the private sector. The most likely Government role, however, is leadership and economic participation on a limited basis, where private industry, in recognition of potential gains, shares the economic risks. In addition, Government control of demonstration programs without the stimulus of a competitive environment could easily produce results of limited economic and social value.

TABLE 6.10. VARIOUS ROLES THE GOVERNMENT MAY PLAY IN DEMONSTRATION PROGRAMS

GOVERNMENT ROLE	ADVANTAGES	DISADVANTAGES
FULL AND SOLE PARTICIPANT	POTENTIAL EFFICIENCIES, DUE TO FULL GOVERNMENT CONTROL EFFECTIVE CONCENTRATION ON IMMEDIATE PROBLEM AREAS EASE OF COMPREHENSIVE AND COORDINATED TRANSPORTATION PLANNING	HIGH COST TO TAXPAYERS POTENTIALLY STIFLING OF PRIVATE INDUSTRY LACK OF REQUIRED SKILLS AND FACILITIES NOT ENTIRELY CONSISTENT WITH DOT ACT
LEADERSHIP AND ECONOMIC PARTICIPATION ON LIMITED BASIS	FLEXIBLE LOW LONG-TERM COST ACCOMMODATES EFFECTS OF MARKET FORCES CAN WORK TOWARD ECONOMIC SELF-SUFFICIENCY PLACES RESPONSIBILITY FOR RISK-SHARING ON PRIVATE INDUSTRY ACCOMMODATES POLITICAL FACTORS	ORGANIZATIONALLY CUMBERSOME SOMEWHAT UNRESPONSIVE SHORT-TERM COST
ECONOMIC PARTICIPATION (SUBSIDIES)	COMPLIES WITH DOT ACT SIMPLICITY AND SPEED	HIGH COST TO TAXPAYER LACK OF CONTROL LIMITED VALUE OF RESULTS DIFFICULTY OF JURISDICTIONAL COORDINATION RESTRICTIVE IN TERMS OF PARTICIPATION OF GOVERNMENT AGENCIES
LEADERSHIP AND DIRECTIONAL PARTICIPATION (REGULATORY)	LEAST TAXPAYER COST COMPLIES WITH DOT ACT CAN TAKE FULL ADVANTAGE OF COMPETITION	LIMITED IN APPLICABILITY IN SOME PROBLEM AREAS LIMITED IN SCOPE RELATIVELY SLOW PROGRESS

Government interaction in this role would include:

- Selecting probable demonstration areas, setting goals, and assessing expected benefits.
- Requesting proposals from private and public organizations, outlining concepts for conducting demonstrations.
- Awarding contracts (with partial funding) for most promising proposals.
- Remaining in a supervisory capacity, assessing progress, resolving jurisdictional problems, resolving legal and procedural restrictions, and obtaining cooperation of local and regional governing agencies.
- Modifying operating criteria as necessary.
- Assisting organizations with development of a testing and analysis plan and performing program reviews as necessary.
- Issuing Government reports summarizing findings and initiating Government policies (if successful) to permit implementation on broadest possible scale.

Benefits

While each specific proposal must be assessed on the basis of the benefits of time saved, land use, and dollars saved, the overall gains that can be realized by making proper use of demonstration programs may be appreciated from the fact that, with only four airports at the saturation point today, capacity limitations are already costing the nation more than $623 million per year. It is expected that by 1985 20 to 30 airports will be saturated with a correspondingly great increase in cost to the Nation. It has been estimated that the New York area alone will suffer a loss of $600 million per year by 1980 as a result of insufficient capacity. Subsidies to local service carriers currently amount to about $34 million per year. These costs should stimulate the search for new ways of solving the current problems of air transportation.

Recommendations

Demonstration Airports. It is recommended that the Federal airports including NAFEC and Edwards Air Force Base (or suitable alternatives) be designated demonstration airports. Aircraft manufacturers have traditionally used a wide spectrum of demonstrations to validate and test the utility of new aircraft. Now, demonstration airports are required so that *systems* choices and their alternatives can be clearly understood. It is believed that this is the most expeditious way to arrive at a balanced air transport system.

High-Density, Short-Haul System Demonstration. Just as have previous studies, the present Study shows the need for a short-haul system designed to meet the needs of high-density corridors. Because this market is particularly sensitive to door-to-door travel times, there is also a particular need to assess the combined effects of airport location and land costs, vehicle characteristics, airport access, CAB/FAA regulations, and air traffic control procedures. At present, an impasse exists with the manufacturers, airlines, cities, and Government regulators, each waiting for the other to take the first big step. Because of this impasse and the difficulty of optimizing this complex system, the Federal Government should take steps to initiate action through demonstration programs. Cities should be encouraged to build STOLports; a favorable regulatory environment should be created; the necessary changes to the ATC system should be made; and, if needed, financial support for initial operations should be provided. Preliminary analyses of a short-haul system demonstration for the Northeast Corridor indicate that initial annual income will be $4 million less than costs, but a well-designed system shows the promise of doing much to relieve congestion in that area by utilizing existing airports more effectively and permitting new airports to be established on significantly smaller parcels of land.

It is recommended that the Government assist in the definition of a spectrum of time/cost/service variations that will be examined

during the demonstration. This experimentation may not be self-supporting at the start, but the information gained should permit a system design responsive to the public's needs and thus capable of attracting sufficient patronage to be profitable.

Low-Density, Short-Haul System Demonstration. Even with the more favorable economics of jets, the short-haul market as a whole has continued to lose money. A large percentage of the passengers today use this service, and yet it is necessary for the Government to provide a $34 million per year subsidy. Ground costs are an important element, but there is evidence that a small vehicle (20–40 passengers) designed especially for this market could significantly improve the situation and find broad application. It also appears that new marketing techniques are needed. Because the effects these changes would have on the market are not known, a demonstration program should be initiated that would involve:

- The evolution of an improved aircraft to serve this market
- Removal of the 12,500-pound restriction for commuter airlines and air taxi operations
- Creation of a regulatory environment by CAB that would encourage carriers to give greater attention to short-haul service
- Experimentation with methods (technical and other) by which flight-crew labor costs could be reduced
- Experimentation with fare and frequency of service, to provide data for airlines in structuring their operations

Airport Capacity Demonstration. Improvements to a number of existing airports are urgently needed. Experiments are needed to study runway layouts, high-speed turnoffs, computer-controlled ground-traffic management, runway spacing, and wake turbulence dissipation experiments. Some of these experiments should take place at a remote and flexible facility such as Edwards Air Force Base (where runways and turnoffs can be simply painted on the large dry lake, and thus can be easily changed in the experiments), and others at NAFEC (where experiments in air traffic control can take place in a realistic operating environment). Other experiments are recommended to assess the effect of charging lower fares at off-peak hours or of varying landing fees to encourage operation at other than peak hours.

Airport Design Demonstration. As passenger volume increases, the natural tendency is to increase airport size. It has become more and more difficult, however, to acquire additional land at existing airports. It may be desirable, then, to use airports exclusively for aircraft operations, moving passenger-handling facilities to off-airport, and more conveniently located, sites and providing high-speed ground-transport links to the airport. Such centralized passenger- and cargo-processing centers, with rapid access links to the airport, offer great promise in reducing congestion at the air terminal. (More than 50% of the people at terminals today are visitors or friends and relatives of travelers.) This demonstration experiment could show the effect of off-site processing on airport congestion, door-to-door time savings, relative costs of operation, and public acceptance. The off-site airport-operator-owned processing centers could experiment with integrated parking, ticketing, baggage-handling, and seat-selection techniques. The traveler would, in effect, have "made his flight" once he reaches the processing center, thus eliminating the need for him to allow a time margin at the airport. The off-airport sites should be easier to obtain than the large blocks of land required to provide all the services at the airport.

Market-Sensitivity Demonstration. Rate and route regulations were originally imposed to foster and strengthen air transportation while it was developing. This objective has now been largely accomplished, and the need for, and the effects of, further regulation should be examined. There are, however, not sufficient data to assess the effects of allowing air carriers to set their own

rates and to serve routes with minimum restrictions. For this reason, a regulatory demonstration program should be considered. It could involve designating, for example, 25 city pairs as open to free competition. Data could then be obtained on the level, quality of service, and profits that result from allowing airlines to establish their own rates, routes, and promotional offerings. These and other experiments could provide data for the evaluation of the need to make some routes competitive, some noncompetitive, and some limited; to use fares varying with the time of day to smooth out travel peaks; to offer minimal passenger services in flight; or to offer service at alternate (less congested) airports at lower rates.

Such experimentation with regulations on a controlled basis will give a clearer picture of present market conditions and sensitivities. This, in turn, can lead to the use of aircraft incorporating more innovative R&D.

REMOVAL OF REGULATORY AND LEGAL CONSTRAINTS ON INTEGRATED TRANSPORT SYSTEMS

Issue

Should the Federal Government reconsider the antitrust and regulatory policies on multimodal transportation activities? If so, how should the policies be modified? The objectives should be to:

- Remove deterrents to systems integration in the movement of people and goods.
- Provide an environment more conducive to intermodal R&D.

Status and Trends

Legal and regulatory constraints to intermodal integration have had a significant effect on the development of not only civil aviation but transportation generally. Justified initially by the uneven growth of transport modes and the need for protection against monopoly, these laws and regulations have accumulated over the past half-century. Their present validity should be reexamined in light of current operations and requirements.

At least four Governmental and advisory groups have recently studied various aspects of the question of intermodal constraints. In January 1971, the report of the President's Advisory Council on Executive Organization (the Ash Council) advocated a single transportation regulatory agency (ref. 29). A study group under the auspices of the National Academy of Sciences (the National Research Council's Maritime Transportation Research Board) has just completed a project entitled "Study of Legal Aspects of Intermodal Transportation" (ref. 30). The study group concentrated on through rates, uniform common liability, and simplified trade documentation, primarily as they relate to the international movement of freight between inland points in the United States and foreign countries. The Transportation Subcommittee of the Cabinet Committee on Economic Policy is considering regulatory reform. The President's Advisory Council on Management Improvement (the Schriever Council) has selected transportation as its first area of study. The 1971 Economic Report of the President contains a section on deregulation of the transportation industry (ref. 31).

Legal and regulatory constraints that discourage coordination between transportation modes also discourage intermodal R&D and innovation. Regulatory and other institutional constraints (such as different State transportation laws, and labor unions), tend to blunt the R&D incentive, and with it, the managerial initiative to pursue R&D. Consider the area of containerization. Differing State highway restrictions led the two pioneers in container ships (Sea-Land and Matson) to develop different length containers – 35 and 24 feet long, respectively. The absence of through joint rates and uniform systems of through liability for intermodal travel has retarded the growth of containerization and hence has inhibited improvements in shipping costs, delivery time, theft, and damage reduction.

A more sweeping impact with respect to R&D exists in the area of air cargo. As indicated in the "Air Cargo" section, air shipment of goods is revolutionizing traditional means of manufacture, distribution, and inventory storage (the total distribution cost effect). Innovations to minimize door-to-door time and costs require coordinated and compatible activities in aircraft design, ground-handling equipment, airport location, facilities, traffic mix, terminal processing and storage facilities, containerization, documentation, airport access/egress, shipment consolidation and scheduling, shipment security and liability provisions, ground vehicles, and surface distribution. Technological innovation in any one link of this chain is inhibited unless complementary innovations in other links are also assured. It is clear from an examination of regulatory case interpretations, however, that strong inhibitions are placed against intermodal coordination.

The problems arising from legal and regulatory constraints are outlined below:

Specific Operational Problems. Of daily concern to shippers and carriers in the air transport industry are costs associated with documentation, tariffs, joint rates, and through liability. In each of these areas a widespread belief is held by shippers and carriers that present intermodal practices could be simplified and improved. These problem areas are closely related; for example, joint rates and common liability limits would provide a strong impetus to simplified standard documentation, including filing tariffs for all modes in standard formats – with resulting cost decreases.

International documentation for shipments currently costs all parties involved, including the U. S. Government, at least $5 billion a year, or roughly 10% of the gross value of our international traffic. The estimated documentation cost of a typical export shipment in 1968 was $163. When one considers that approximately 25% of the shipments exported from the United States are valued at less than $100, it is clear that documentation costs are excessive.

Experience has shown that a common form of contract is greatly beneficial to trade. For example, the creation by the banking industry of standards for checks and other documents has facilitated commerce. In contrast, there does not exist today a common bill of lading for the various modes of transportation. If such a form existed, a shipper could prepare, in cooperation with the first carrier, a single document, setting forth the conditions of carriage and limits of liability for the entire movement, which would be acceptable from origin to destination. It would also comprise a waybill, serving as a receipt for the cargo. Ideally, the single bill of lading would satisfy banking, insurance, and customs requirements.

Insistence on preserving tradition may make it very difficult to arrive at a common bill of lading. However, much effort is being made to simplify shipping documentation in general. Both private and public groups, including the National Committee on International Trade Documentation and the Office of Facilitation of the Department of Transportation – are involved. DOT supported the "Trade Simplification Act of 1969" (HR 14489; S 3142) that, had it passed, would have authorized inland and ocean water carriers and air carriers to enter into agreements to establish joint rates and issue a through bill of lading from origin to overseas destination.

Intermodal transportation is hampered by the fact that tariffs are not filed before the three regulatory agencies in a common format, which would refer to commodities in a standard way. Today, a commodity may be measured in terms of volume on one mode and in terms of weight on another mode. Again, there are groups at work on the problem, but a much greater effort is required.

With joint rates agreed to by carriers of different modes, a shipper could determine his shipping costs for an intermodal movement easily and definitely (x dollars for delivery in y hours, regardless of modes used). The three transportation regulatory agencies recognize the possibility

and even the desirability of joint rates made by carriers of the *same* mode, and recently intermodal joint rates have been receiving more attention. Rail-rail joint rates are recognized, and indeed are mandatory among domestic rail carriers. Joint air-surface rates are permitted but not mandatory, although joint rates between air freight forwarders and ICC–regulated carriers are not yet permitted. The ICC and the Federal Maritime Commission have recently agreed to the filing of joint land-water rates.

Other inconsistencies are aggravated by the existence of three separate regulatory agencies and numerous statutes. Although the proposed Trade Simplification Act sought to widen the use of intermodal joint rates, it left a number of important questions to the discretion of the separate regulatory agencies; for example, whether the division of the joint rate between the carriers should be known only to the carriers, as is the Interstate Commerce Commission practice, or whether the division should be stated in the tariff, as is the Federal Maritime Commission practice.

Separate transport modes also operate under many different statutory limits of liability, including the "Warsaw" convention for international air carriers, the Carmack Act for domestic surface carriers, and the Carriage of Goods by Sea Act of 1936 (known as the "Hague Rules") for ocean carriers. Under present transportation practices, it is difficult for the shipper to determine with which carrier damage occurred and, therefore, how to collect for damages. The result is uncertainty, complexity, and unnecessary duplication of insurance by both shippers and carriers.

Administrative and Organizational Problems. When economic regulation in civil aviation was established (with the passage of the Civil Aeronautics Act in 1938), the air transportation market was infinitesimal, with revenues of $57 million compared with those in 1968 of $796 billion (ref. 27). At the time economic regulation was first put into effect, it was considered essential on the grounds that:

- Transportation could easily become a monopoly, with monopoly pricing – thereby restricting the growth of air transportation.
- Economic regulation would protect the weaker carriers.
- Economic regulation was desirable since subsidy was to be paid, and this was necessarily accompanied by restriction of entry and control over rates, routes, mergers, etc.

In the past 30 years, however, air transportation has been fundamentally transformed by advances in technology, growth in markets, massive investments, and strong competition. Travelers and shippers now usually have a wide range of choice of routes, services, and even modes. The number and variety of transportation alternatives available today has made comprehensive regulation administratively cumbersome (in 1969 there were more than 7,000 formal proceedings by the ICC and nearly 1,200 dockets before the CAB) and has led to economic suboptimization.

The price of regulation is high. Delays inherent in the regulatory process are costly, preventing rapid innovation and adjustment to changing economic conditions – for example, building up surplus working capital in anticipation of massive capital investment in new equipment, or quickly covering costs of wage settlements. The regulatory process encourages protective policies, and industry management tends to be preoccupied with procedural strategy rather than with R&D innovation and efficiency. Air carriers are unable to develop optimal schedules and route patterns. It is not that the agencies have been generally unsympathetic to new development – usually quite the contrary. But the tendency (and indeed statutory direction) has been for the agency to *wait for the problems to be presented to it* and to deal with them in a piecemeal fashion.

With the maturing of all transport modes and the increase in intermodal transportation, prohibitions in one special area of regulation – the common ownership of more than one transport mode – are undergoing review and change.

Historically, surface carriers have been prohibited from acquiring air carriers unless they could show that aircraft could be used to public advantage in their operations and would not restrain competition. Although the law does not actually prevent a surface carrier from entering air transportation by means other than acquiring an air carrier, the CAB has insisted that such transactions meet both the public interest and conflict of interest tests, where air traffic might be significantly diverted to the other modes.

Air carriers are not, however, prohibited by law from acquiring other transport modes, although such acquisitions must be submitted to the CAB for approval. These transactions must meet public interest and conflict of interest tests; that is, the prospects of competition between the modes must be slight and the possibility of traffic being diverted from air transportation must be remote. Overseas National Airways, a supplemental carrier, recently proposed to create a subsidiary that would own and operate a passenger cruise vessel. The CAB examiner disapproved the application on the grounds of potential conflict of interest.

The CAB's concern with preventing possible diversion of air traffic through an intermodal acquisition has discouraged intermodal mergers. A few proposed mergers, however, have overcome this restrictive obstacle. Transamerica Corporation, which owns Trans International Airlines (a supplemental carrier), was recently permitted to acquire Lyon Van and Storage Co., presumably because there was little likelihood of a conflict of interest. In addition, railroads and long-haul motor carriers have recently been permitted to enter the field of air freight forwarding, either through acquisition or original entry.

To further complicate the problem, usually several agencies have an interest in any carrier that might be involved in intermodal transportation. Jurisdictional conflicts have arisen; pickup and delivery problems and the definition of commercial zones in which air freight forwarders are authorized to deliver have generated interagency conflicts.

Examples of the advantages of intermodal mergers can be found in both cargo and passenger transportation. The advantage of common ownership, which is of particular interest in this Study, is the more rapid introduction of new intermodal technology. Canadian Pacific provides an obvious example with its ownership of a railroad, airline, and pipeline, as well as trucking and steamship operations. The earlier development of large scale Piggyback service in Canada than in the United States can be largely explained by Canada's much less restrictive legislation on multimodal ownership. The vested interests of the separate transport modes and difficulties in agreeing on intermodal equipment (including containers) and facilities tend to retard intermodal technology. Not only would multimodal ownership provide a central responsibility for initiating intermodal R&D, but by enabling the innovator to capture the full profit of his technological improvement, the economic incentives for pursuing new technology would be increased.

In the case of passenger transportation, it seems clear that legal and regulatory constraints are inhibiting innovation, research, and development aimed at reducing the ground access time to and from the airport, as well as airport processing time. Certainly, institutional and policy considerations such as multiple political jurisdictions, strong funding emphasis on highway versus public transit, and the importance of parking and concessions to airport revenue strongly affect the incentive and capability for innovating total systems processing of passengers.

Government Involvement. The alternatives open to the Federal Government in modifying legal and regulatory constraints on integrated

transportation are: to continue present policies; to increase cooperation and coordination; or to institute more sweeping reform. With the diversity in nature, magnitude, and complexity of problems associated with legal and regulatory constraints, one alternative may be appropriate for alleviating some problems but inappropriate for others.

- *Continue Present Policies.* Extrapolating the current trend would help solve some of the specific operational problems. Both the DOT and the transportation regulatory agencies have undertaken to solve selected aspects of the problems.

The creation of DOT has had a definite influence on intermodal cooperation. Members of DOT's Office of Policy Review and Coordination have testified at hearings before the regulatory agencies. The Office of Facilitation has exerted its efforts towards simplifying trade documentation, facilitating container interchange between modes, and encouraging a uniform system of carrier liability. The DOT–supported Trade Simplification Act, as previously mentioned, would have permitted common carriers of one mode to establish joint rates with common carriers of other modes for the international transportation of cargo and would have permitted a carrier to issue a through bill of lading. The carrier would have assumed responsibility for the cargo for the entire trip. The Act would not have solved the problem of the absence of a simple and uniform system of carrier liability. The sponsors of the bill realized that any restructuring of the many conflicting domestic liability laws and international conventions was unlikely in the short time, but believed that permitting joint rates and through bills of lading would provide an impetus for cooperative private and public attacks on the liability problem.

Although the CAB has tended to move toward free entry into air freight forwarding, questions of common ownership involving the direct air carriers continue to be interpreted in a restrictive manner. With other agencies, the current approach to common ownership is essentially passive, each question being answered on a case-by-case basis. This is normal and correct quasi-judicial procedure, but with the number of different agencies involved, it does little toward assuring a broad and intermodal consideration of the matter.

There are advantages in continuing the present policies. This alternative is the easiest to follow and it is the least costly in terms of additional effort required. More importantly, under the present policies, considerable effort is being exerted to remove some of the specific operational impediments to intermodal transportation.

The disadvantages are that the broad aspects of the issue – common ownership of separate modes, the status of the three regulatory agencies, and the questions of deregulation – are not being treated thoroughly, if at all. This alternative can be characterized as a piecemeal approach, since many statutory inconsistencies will remain, leaving today's fragmented systems to continue. Modal views may be expected to continue to predominate, and intermodal problems will continue to be treated on a case-by-case basis by the regulatory agencies.

- *Increased Cooperation and Coordination.* In this alternative, the Government would accept the existing regulatory framework and strive to make incremental improvements within this framework. Generally, the three transportation regulatory agencies would work more closely with each other as well as with DOT and with other departments.

The regulatory agencies could adapt their procedures more to dealing with intermodal questions by holding joint meetings on important intermodal questions – even though such meetings are cumbersome – and by encouraging representatives of one agency to appear before another agency.

The regulatory agencies would work together and with carrier and shipper representatives to develop common procedures and forms, such as the single bill of lading, common tariff formats (including tariffs for joint rates) and simplified and standard commodity codes. Where forms would be used in international transportation, foreign governments and the Bureau of Customs would in some cases be involved. Such common forms would greatly reduce the amount of paperwork in intermodal transportation, at a saving to shippers, carriers, and the governments involved. A spokesman for the National Committee on International Trade Documentation estimates that with the cooperation of the Government, the cost of international trade documentation could be reduced from $5 billion to half of that within a 4- to 5-year period. Many procedures and forms are amenable to joint agency efforts. Although active interagency cooperation and coordination are difficult, the effort would be an improvement over the more passive approach of the preceding alternative.

Although the statutory inconsistencies and the numerous international conventions on the limits of liability for carriage by different modes create a particularly difficult and time-consuming obstacle to rapid improvement, the agencies, in conjunction with the DOT, could bring some order to the problem. The agencies could cooperate in developing and issuing rules concerning from whom and where to collect for damage or loss to an intermodal shipment. Similarly, procedures for apportioning liability among carriers could be recommended. The larger problem of conflicts in statutory liability limits and international conventions can be resolved only through joint Government-industry cooperation on the domestic conflicts and international negotiations on the international conflicts. A uniform system of liability may be impractical and perhaps even impossible for all domestic and international intermodal transportation, but certainly greater order can be brought to the present situation.

On the subject of common ownership of carrier by different modes, the three transportation regulatory agencies, in conjunction with the Departments of Justice and Transportation, would study the problems with the purpose of developing, for presentation to the Congress, a new policy to assist the establishment of intermodal systems in the public interest, with appropriate safeguards. The safeguards might include the following criteria:

- The proposed merger should result in operational benefit and in financial benefits not otherwise obtainable.
- Competition should not be materially lessened.
- Internal subsidies should be minimized.

This approach of increased cooperation and coordination to modify legal and regulatory constraints has definite limitations when the broader aspects of the issue – particularly the status of the three transportation regulatory agencies and the question of deregulation – are considered.

- *More Sweeping Reform.* A more far-reaching alternative would include the adoption of the single transportation regulatory agency as proposed by the Ash Council (ref. 29) and adoption of degrees of deregulation.

The Ash Council has proposed replacement of the three transportation regulatory agencies with a single agency and a single administrator appointed by the President with no set term of office. The promotional (subsidy) role of the CAB would be transferred to the DOT. The Council has recommended that the common agency and its single administrator be formed before the bulk of the transportation regulatory legislation is rewritten. The following reasons are offered:

- The merger would otherwise be unnecessarily delayed, since with over 80 years of regulatory statutes, the legislative rewriting would be an extremely complicated and time-consuming process.

- The administrator could provide strong help in rewriting the statutes.
- Interagency coordination has not been very successful, judging from past experience. Under separate agencies, the process of rewriting would be even more time-consuming; agencies would be less willing to compromise, less willing to consider intermodal aspects, and less willing to give up part of their jurisdiction.

The advantages of a single agency are:

- Inconsistencies in transportation regulatory policies – including common ownership of separate modes – would be removed.
- Regulatory and promotional aspects of transportation would be completely separated.
- A more intermodal view would be adopted.
- Trade simplification – documentation, joint rates, and through liability – would be facilitated.

A single administrator would be expected to:

- Develop policies and promulgate rules of broad applicability.
- Lend more weight to the process of hearings, since the regulatory bodies now constituted tend to overjudicialize.
- Coordinate more easily with the Secretary of Transportation and other Cabinet-level officials.

Some observers maintain that a single agency is unnecessary, that the policy inconsistencies can be removed through legislation and increased cooperation and coordination, and that, after all, most of the transportation regulatory problems are modal rather than intermodal in nature. The Congress, however, may not be sympathetic to a merger, and the transportation companies being regulated would almost surely oppose such a reorganization.

Deregulation of air transportation is a fundamental change that has been considered in the past and is again receiving serious study despite the air carriers' current economic regulation: controls on rates, routes, entry, and mergers would be relaxed over a period of years. The phasing would provide time to observe the effect of a gradual deregulation, to change the degree and speed of the deregulation, and to ensure an orderly transition to a stronger free-enterprise basis of competition. Deregulation would affect only the economic sphere of operations; safety regulations would not be affected.

Regulation would not have to be eliminated entirely. For example, some rate control on fares may be necessary to protect less competitive parts of the market from predatory practices. But the direction toward deregulation has been signaled; in the current fare-structure investigation by the CAB, DOT recently proposed that air carrier fares be permitted to fluctuate by ±15% (ref. 32).

In the process of deregulation, both rates and routes could be freed simultaneously, allowing an air carrier to vary its fares by as much as, say, 15% the first year, 25% the second year, 40% the third year, and so on. Routes could be deregulated according to a schedule that permitted an air carrier to discontinue up to 10% of its route mileage the first year or expand its route mileage by as much as 10% the first year, 25% the second year, and so on. After the phased deregulation had proceeded for sometime, entry into air transportation would no longer be controlled except for safety reasons. At the very least, antitrust provisions would apply, with some criteria similar to those given in the above paragraphs on common ownership.

Any degree of deregulation would free industry management to concentrate more on efficient management of air transportation. Although it would not remove all institutional constraints, deregulation would at least remove one important obstacle to innovation, including the pursuit of R&D. If deregulation is considered for other

transportation modes, the need for uniform deregulation of the modes would provide another advantage of a single regulatory agency.

Deregulation may result in some certificated carriers discontinuing some unprofitable routes, particularly short-haul. Although a number of these routes may be picked up by other carriers (probably at a higher fare) some smaller communities would lose air service altogether. If it were in the public interest to maintain these routes, the Government could selectively subsidize them.

Recommendations

- The floating fares advocated by DOT before the CAB's current fare investigation should be implemented, and further deregulation should be considered.
- Although revision of the regulatory statutes to resolve the inconsistencies in, and modal approach to, common ownership of separate modes, will not be easily accomplished, the issue warrants early resolution. Without waiting for the creation of a single transportation regulatory agency, the existing agencies, with the Departments of Transportation and Justice, should develop a new common policy toward intermodal systems.
- Many of the specific operational problems – simplification of trade documentation, joint rates, and aspects of through liability – would be solved in the statutory revisions accompanying a merger of the regulatory agencies. Other efforts to solve the problem, however, should be continued in the meantime and even accelerated. Increased cooperation and coordination among the agencies and with the DOT would be useful in simplifying and standardizing intermodal trade procedures and forms – single bills of lading, common tariff formats, simplified and standardized commodity codes, joint rates, rules on apportioning liability among carriers, and common rules on whom and where to sue. The resolution of statutory inconsistencies, particularly in the field of through carrier liability, deserves greater cooperative efforts, legal research, and international negotiations toward removing these obstacles to achieving efficient intermodal transportation.

AIRPORT LAND ACQUISITION AND AIRPORT LANDSIDE DEVELOPMENT

Issue

What role should the Government assume to assure that airport development programs are accomplished in a more timely manner? What methods should be used to achieve a better integration of the landside of airports (access/egress, terminal processing, etc.) with the other parts of the air transport system?

The objective is to:

- Increase the pace of development for new and improved airports, since airports have the longest lead time of any element of the air system.
- Help eliminate congestion.
- Develop a more balanced system, able to take full economic advantage of increased aircraft productivity.

Status and Trends

Increasing use of air transportation has produced congestion in airport access/egress systems and airport terminals that threatens to limit the capacity of many major U. S. airports to much less than their airside capacity. For example, it is anticipated that 80 million people will use Los Angeles International Airport in 1975, but the highway capacity as it is now planned for 1975 will handle only 40 million people. Several of the modal agencies in DOT, as well as the Department of Housing and Urban Development and the Economic Development Agency, are involved in airport landside development, but no one agency has

responsibility in all areas. This fragmentation militates against effective Federal action. This is especially important because there is a strong dependence on Federal assistance to airports, which arrives from the long-standing Federal involvement in:

- Federal Aid to Airports Program
- Airport Development Aid Program
- Airport access, through highway funding
- Air traffic control
- Air vehicles and new airport certification

Active Federal leadership is essential to adequate integration of airport systems into the overall air transport system. While such past Federal activities, as these have been in the past, in this area have been generally successful, current efforts appear inadequate because of the rapid growth of many external factors – for example:

- Environmental problems such as noise and air pollution
- Extensive airport modifications required by the introduction of wide-body jets
- Facilities needed to meet projected air cargo growth
- Rapid urban sprawl resulting in losses of suitable airport land

The problem is particularly difficult since site selection and development of a new airport and its supporting facilities can take from 10 to 15 years. As a result of these delays, demand continues to outstrip available capacity. The problem is often made more difficult when actual growth exceeds forecast growth. In addition, an airport is difficult to modify if it proves to be inadequate. A vehicle can be modified relatively easily and the ATC system can and has evolved, but a mislocated, undersized airport, hemmed in by urban sprawl, with inadequate access facilities, is very expensive to change. Long-range planning is very important. Early land acquisition and proper balance between the development of airside and landside facilities are vital to adequate airport capacity and, thus, to the future growth of air transportation.

Land Acquisition. Recent difficulties in reaching agreement on new sites for major airports in the New York, Miami, Chicago, New Orleans, and Minneapolis–St. Paul areas make it clear that the acquisition of land for new airports will be a major problem in the foreseeable future. The Airport and Airway Development Act of 1970 (ref. 33) authorizes the Federal Government to provide up to 50% of the cost of land acquisition for any airport that the FAA has included in the National Airport System Plan. Although the new Act provides for a planning period of at least 10 years – twice as long as did the former Federal Aid to Airports Program – the difficulties in obtaining agreement on site locations can be expected to continue unless further action is taken. State or local policies have, in the past, provided little financial incentive for advance land acquisition. Without some financial aid, local airport sponsors will not be able to finance advance acquisitions. Statutory authorizations of power to take property for airport use by eminent domain have traditionally been upheld. However, because condemnation by eminent domain is politically unpopular and costly, long-range airport planning will probably not rely on this procedure.

The recent acquisition of 84,000 acres of land for airport development in Toronto by the Canadian Government warrants the attention of the U. S. Government. By comparison with the acreage of some of the largest and busiest U. S. airports, this is a huge tract of land for airport development. For example:

Airport	Size (acres)
Washington National	860
Kennedy	4,900
O'Hare	6,521
Dulles	10,000
Dallas/Ft. Worth	18,000

Examination of the histories of many of these airports indicates that the size of the *initial* purchase of land tends to be the ultimate limit to the size of the airport – later land acquisition becomes inordinately expensive.

Coupled with land acquisition is the need to assure zoning compatible to the airport as an activity center. The power to zone near airports has, in some instances, been pre-empted by State statute but more usually is delegated to a local political subdivision, pursuant to a State enabling statute. Zoning has never been thought of as an appropriate activity for the Federal Government, but there appears to be no constitutional impediment to the enactment of Federal legislation on airport zoning pursuant to the Federal power over interstate commerce. With the Government now entering airport certification, it is possible and even desirable that the Federal Government begin to exert more leadership regarding zoning around airports.

Complementary Ground Transportation. The origin and destination of trips to and from an airport are distributed throughout the urban area served by the airport. Airport access/egress must therefore be taken into consideration as part of the overall demand on the urban transport system. Airport access/egress planning has frequently been neglected, as in the case of Atlanta and Minneapolis–St. Paul. This is partly a result of differences in Federal funding policies for various transportation modes. Federal assistance for construction of transportation facilities currently favors highway construction by providing up to 90% assistance from the Highway Trust Fund. For mass (public) transportation the maximum is 67%. Financial problems usually motivate local authorities to pick an airport access/egress approach that minimizes costs but may not minimize door-to-door travel times. As a consequence, the traveler must allow large time allowances (safety factors) for getting to the airport, parking, ticketing, baggage-handling and seat-selection. For example, the Official Airline Guide shows a time of 75 minutes by limousine from the East Side Terminal in New York City to JFK; under favorable driving conditions this schedule provides a 40-minute safety factor (ref. 34). These necessary time allowances are particularly annoying and inconvenient for the short-haul passenger; the ground portion of his trip may well take longer than the air portion. Most travelers would welcome more attention to the ground portion of their trips. New approaches are needed. Any such system should also provide for door-to-door package service.

One impediment to progress through applying the systems approach to airport access/egress and terminal processing centers around the economic aspects of airport management. There is an incentive to keep transit links out of the airport because of the importance of parking revenues. Concessions – an important source of revenue – are often given more attention in terminal layout and procedures than is passenger processing. In the fiscal year ending June 30, 1970, Washington National Airport received more than twice as much revenue from parking and concessions than it did from landing fees ($5,069,000 in parking; $2,334,700 from landing fees). At JFK, approximately 50% of the arrivals and departures are by automobile, and at times the demand exceeds parking lot capacity. Little urgency is being demonstrated to finding relief for congestion. Extensions of bus service to JFK have been opposed and a proposal by American Airlines to provide a parking garage near its terminal was refused. For whatever reasons, the user finds that many of the advantages offered to him by air transport are being eroded away by difficulties with the ground portion of his trip.

Processing of Passengers and Cargo at the Air Terminal. The terminal and the services it offers need to be considered more carefully as a system. The analysis of terminal performance is difficult. A terminal may provide good service to a business traveler with a direct flight and no baggage to ckeck, but may provide poor service to transferring between airlines or to originating passengers with several bags, accompanied by visitors. There is no single approach to terminal design significantly superior to all others. Certain designs serve some passengers better than others. Design criteria and performance measures for terminals are not well understood. Research in these areas is needed.

Devices designed to manage parking, ticket and handle baggage, and move people through the airport terminal, in general are not developed with the requirements of other parts of the system in mind. Cargo-handling and cargo movement around the airport compound ground congestion, suggesting the need to consider off-airport cargo processing and even all-cargo airports.

Remote processing of passengers is also worth study. A recent survey at Cleveland-Hopkins Airport showed that of the 213,800 weekly person-trips to and from the airport, 36% were air *passengers*, 46.5% were *passenger-related visitors*, 13.9% were *employees*, and 3.3% were *casual visitors* (ref. 35). Off-airport processing could relieve much of the load, keeping almost half of the people – the passenger-related visitors – away from the airport. With careful planning, remote terminals could be located near existing or proposed rail links. Bus and limousine transportation could be used until rapid rail links could be established. Similarly, cargo-handling facilities could be located off-airport and linked with the airport by high-speed rail. These steps would permit using land around the airport more effectively for operations associated with the airside.

Government Involvement

Rationale. All of the separate elements of the air transport system come together ("interface") at the airport. The location, the capacity, and the other characteristics of airports have an important influence on the operations and the efficiency of the entire air transport system. In many areas, the airports already represent a bottleneck to future growth of civil aviation. Forecasts suggest more severe problems in the future. Increased attention should be given to the relationship between airports and the national transport system. Historically, the Federal Government has provided financial assistance in the development of airports. Continuation or expansion of this role is appropriate because of the importance of the airports to the system and because the benefits that will accrue as a result of adequate airport development will extend beyond the direct user to the region and to the Nation.

Role. Federal involvement can take the following forms:

- Leadership and participation in direction. This role can include such things as elimination of legal or regulatory barriers (to stimulate door-to-door travel) and analysis of airport design criteria and operational requirements. This role is very appropriate because data are lacking, a systems perspective needs to be established, and institutional factors under the control of Government are inhibiting action by private industry.
- Economic participation through trust funds. The Federal Government today collects user charges, which are used to improve the overall system. This could include funding for access/egress roads, airports land acquisition, and airways. With this role would go an obligation by Government to analyze the system sufficiently so funds are allocated where they will do the most good.
- Economic participation with public funds through R&D studies on zoning, mass transit requirements, off-site processing, and terminal design. Results of these studies would benefit more than the direct user and thus warrant the use of public funds.

RECOMMENDATIONS

It is recommended that the Federal Government include in its airports program the following items:

Land Acquisition

- Encourage State and local authorities to plan further ahead for new airport land acquisition (e.g., by use of "land bank" systems and economic incentives). The

Airport and Airway Development Act allows 50% Federal participation in land acquisition; advance land acquisition, however, is of low priority. In the case of parks, land is set aside in "land banks" before this national resource is irretrievably lost. Once land is developed for other uses it is very expensive to "reaccumulate" in the very large parcels required for airports. Lack of land for airports can limit the development of an optimal air transport network in the future. Although budget considerations may preclude early land acquisition, the advantages and disadvantages of such requisitions should be more carefully analyzed. These analyses could serve as the basis for adjusting Federal priorities under the Airport and Airway Development Act regarding early land acquisition.

- Establish better information dissemination on land control around airports for State and local planning authorities. Since compatible land usage around an airport is important to realization of its full potential capacity, the Federal Government should explore its opportunities for leadership in zoning through airport certification standards and Airport and Airway Trust Fund release.

Airport Access/Egress

- To help foster the integration of transportation systems, the Federal Government should use highway, rapid transit, and airport aid to encourage local planners to include adequate provision for airport access and egress. To do this, it is recommended that the Secretary of Transportation condition the release of Highway Trust Funds and UMTA funds until adequate plans are developed for access links to airports. In addition, DOT should encourage the formation of unified State transportation agencies to promote the development of a balanced and integrated transport system.
- Investigate how the four airports where demand now exceeds capacity could receive immediate additional funds for extensions of mass transit links to the airports.

Terminal Development and Operation

- The Federal Government should develop and specify minimum levels of service as guidelines for terminal development.
- The possibility for providing better service for interline transfer of passengers should be investigated. Possible alternatives would include giving route structure incentives and dynamic allocation of gates at the airport.
- Airport design R&D should be increased. Studies should be initiated to collect data and identify the needs of the various passenger types and the optimum methods of processing them through an airport. With the information collected, analyzed, and disseminated, the Government should leave the development of people- and baggage-oriented hardware to private business. The Government role suggested here is as a supplier of systems information so individual developments can be readily integrated into a total system framework.
- Air terminal congestion is caused not only by problems on the airside of the terminal, but by problems on the landside of the airport as well. It is therefore recommended that legislation be introduced to allow use of the Airport and Airway Trust Fund for landside problems (up to and including the airport boundary). Currently, the intent of the user charge is to provide a better *aviation system*, financed by those who use it. Neglect of the landside problems will prevent full realization of improvements made on the airside, as well as improved door-to-door service for those who contribute to the fund.

- Quantitative data are lacking on the relative merits of various approaches to solution of the problems on the airport landside. Demonstration airports are required to examine different practices and technology in a systematic way. This information would assist the airport operator in making more optimal choices. It is therefore recommended that several airports be designated as demonstration or experimental airports. Two landside experiments are suggested. Off-site passenger- and cargo-processing centers, with rapid access links to the airport, offer the promise of reducing up to 50% of the congestion at the air terminal. This experiment should be carefully designed to examine the effect on airport congestion, door-to-door time savings, relative costs of operation and public acceptance. Within the processing centers, a second set of experiments covering the development, operation, and analysis of an integrated passenger processing system is recommended. The patron would be guaranteed a seat on a flight once at the processing center. Land required for these processing centers should be easier to obtain, resulting in freeing land at the airport proper for more efficient use of airside elements.

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7. BENEFITS

Benefits

BACKGROUND

As recently as 1940, civil aviation was a negligible factor in the Nation's economy and in our personal lives. In the short span of 30 years its development has been so widespread that it is now a significant element in methods of doing business and patterns of living. An observer in 1940 could not have foreseen the tremendous growth of civil aviation and its pervasive impact on today's economic, social, and cultural environments. The application of the R&D discussed in this Study to civil aviation systems over the next 15 years may be expected to have an equally great impact in our pattern of living by 1985.

History shows that aeronautical R&D has yielded great benefits to the Nation. Continued development of new concepts and their application to economically viable systems will insure a continuation of this stream of benefits. While it is possible to hypothesize on the overall magnitude of these future benefits, it is not possible to quantify them without relating them to specific R&D proposals. A preferred alternative is to evaluate the impact of civil aviation on the country in the past and identify the benefits that have accrued as a result. The following analysis is not a detailed cost-benefit study, it focuses instead on the impact of the aggregate civil aviation system on society over the past 20 years. In the material that follows, the many benefits of civil aviation are assessed but it was not possible to isolate exclusively the particular benefits resulting from individual R&D efforts or levels of effort. Rather, the benefits are treated as the products of the total system operating in a complex environment and making use of the capabilities provided by R&D.

CONTRIBUTIONS OF R&D TO CIVIL AVIATION

Most of the advances in civil aviation – in new types of airframes, propulsion units, and aircraft avionics – can be traced to R&D. These advances have brought about large increases in the productivity of the air systems to the benefit of the users, local regions, and the entire Nation. The industry has made prompt use of new technology. More than 50% of the aerospace industry sales in 1973 are expected to come from products that were not marketed in 1969 (see Table 7.1). This compares with 37% for other transportation equipment. As may be seen from the table, an even greater difference exists between expected new-technology sales in the aerospace industry and those expected in other selected industries (ref. 1). The role of R&D in most of these developments, particularly in the aerospace industry, has been significant.

TABLE 7.1. ESTIMATED PERCENT OF 1973 SALES FROM PRODUCTS NOT IN EXISTENCE IN 1969

INDUSTRY	PERCENT
AEROSPACE	52
OTHER TRANSPORTATION EQUIPMENT	37
INSTRUMENTS	35
AUTOS, TRUCKS, PARTS	30
ELECTRICAL MACHINERY	20
CHEMICAL	17
PETROLEUM	6

Source: Ref. 1.

Substantial improvements in the performance of today's civil aircraft can be related to technical results from R&D efforts carried out since 1945. Many of these advancements in performance can be traced to the introduction of commercial jets

TABLE 7.2. PERFORMANCE OF TRANSPORT AIRCRAFT, 1945, 1970

	1945	1970
SPEED, MPH	200	600
RANGE, MILES	2000	6000
CAPACITY, OVERALL AVAILABLE TON-MILES BILLIONS	1.2[a]	33.2[b]
ECONOMY, CENTS/AVAILABLE SEAT-MILE	3.0	0.9
SAFETY, FATALITIES/100 MILLION PASSENGER-MILES	2.23	0.001

[a]*Earliest published data available are for 1946.*
[b]*October 31, 1969, through October 31, 1970.*
Source: Refs. 2-6.

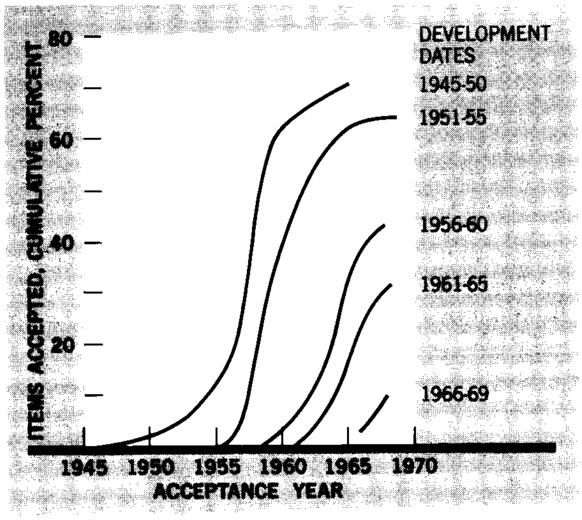
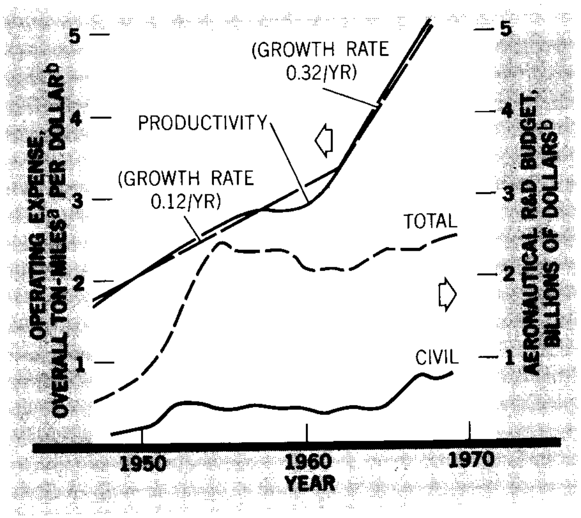


Figure 7.1. Utilization of technical advances in civil aviation (517 events). *Source: Refs. 3, 7.*



[a]*All services.*

[b]*1968 dollars.*

Figure 7.2. U.S. commercial transport productivity index and aeronautical R&D budget. *Source: Based on refs. 2, 3, 7.*

in 1958 – jets that were outgrowths of the B–47, B–52 and KC–135 aircraft, directly attributable to military R&D. Table 7.2 shows the dramatic increase in performance of transport aircraft made possible by R&D in 25 years.

In civil aviation, the acceptance of new developments follows a remarkably similar pattern. A study of the application of 517 R&D "events" (results) (ref. 3) has shown that from 5 to 15 years may elapse between a development event and its application in production aircraft (Fig. 7.1). The benefits of R&D performed in the late 1950's and early 1960's are being realized today. Thus, it is the R&D funds expended today and in the next few years that will contribute many of the advances in the 1970's and 1980's.

Figure 7.2 shows productivity in terms of available ton-miles offered per dollar of operating expense for all carriers. It may be seen that, to a first approximation, the level of effort in R&D in the 1950's has established the rate of growth of productivity of transport aircraft in the 1960's. The measure of productivity selected eliminates some of the effects of demand fluctuation, subsidies, and fare variations that would exist if productivity were expressed in revenue ton-miles. (Unless otherwise stated, all dollar figures in this section are in 1968 constant dollars rather than current dollars, to remove the influence of inflation.)

The growth rate for 1947 to 1959 was 0.12 ton-mile per dollar per year. The slight dip in the curve from 1959 to 1961 was due to expenditures for new jet aircraft, training, and changeover to new maintenance procedures. By 1962, productivity had reached a level almost three times greater than in the preceding period. Figure 7.2 shows that total aeronautical R&D funding increased substantially between 1950 and 1955. Much of the design data required for the development of the jets was generated during this period. One important result was the evolution of the turbofan engine from the turbojet. The greatly increased power of the turbine engine made possible greater payloads and increased speed in the 1950's; the development of the turbofan engine led to more economic air carrier operation in the mid – 1960's. Most of the growth in productivity of commercial aviation can be attributed to the vehicle – and it was the introduction of the turbofan engine that accounted for much of this growth.

It is typical of complex technology systems that most of the advances in productivity in the

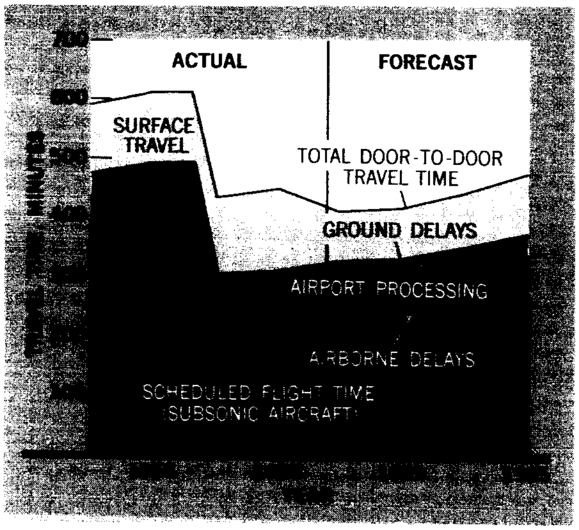


Figure 7.3. Door-to-door travel time for a one-way air trip, Chicago to Los Angeles (1,746 miles).

first several generations of the system result from improvements in the primary element of the system. This has been true with civil aviation as well. For example, Figure 7.3 shows the significant reduction (approximately 33%) in door-to-door travel time that resulted from the introduction of jets into the system. It may be seen from the figure that changes in other system elements have had little or no impact on this particular measure of system productivity. (An exception specific to this example is the slight reduction in surface travel time attributable to the opening of the Northwest freeway connecting downtown Chicago with O'Hare International Airport.)

The dominance of the vehicle in the growth of system productivity can be tied to the historical emphasis on R&D for vehicles. Although the data do not permit separation of military and civil R&D by system element, examination of the distribution of aeronautical R&D dollars from 1945 to 1969 indicates that the air vehicle received over 90% of the total.

It is difficult to assess the productivity contributions and the benefits derived from the other elements of the system – that is, airports, air traffic control, and complementary ground transportation. Their influence can be measured only negatively, to the degree that they prevent the vehicle from attaining its full potential productivity. These supporting elements today are affecting advances in vehicle performance to such an extent that future vehicle achievements may be largely nullified by reduced performance in the other parts of the system. It is important that R&D be applied to all complementary functions if the civil aviation system is to realize its potential productivity.

These changes in system productivity have generated the wide range of benefits discussed in the following sections. The assessments should be viewed as maximum benefits since vehicle performance has been largely unconstrained by the other systems elements during this period and the various benefits are not necessarily additive.

BENEFITS TO THE USER

Throughout the past 20 years, both the individual user and industry have benefited tangibly from advances in aviation technology and services. It is frequently contended that Government support of civil aviation is a subsidy to businessmen and those users who "clearly are not in need of Government support." Yet, it is important to recognize that these people are by no means the sole beneficiaries of civil aviation. An analysis of data from the U. S. Census Bureau revealed that the median family income of people taking one or more trips by air in 1967 was $11,922, while it was $8,021 by car, and $6,759 by train (ref. 8). Although the median income of air travelers is higher than that of travelers using either of the other two modes, it cannot be considered as representative of a mode utilized principally by the well-to-do. People who use air transportation today because of an emergency or because of a short time allowance (servicemen on leave, students or vacationers flying during holidays, or

individuals seeking jobs) represent all segments of society. The benefits are just as important to the occasional or one-time user as they are to the regular user.

Users of the system have realized at least the following benefits:

- Cost savings
- Time savings and increased convenience
- Safer transportation
- Business stimulation

Cost Savings

Because of improvements in aircraft over the past two decades, air carrier unit direct operating costs have dropped from 3 cents per available seat-mile to 0.9 cents per available seat-mile (ref. 3). A substantial portion of these savings has been passed on to the user. If the fare per passenger-mile had remained at its 1948 level from 1949 to 1958, passengers would have paid an additional \$4.1 billion in fares (computed in 1968 constant dollars) (ref. 2). Similarly, if the fare level had not improved in the 1959 to 1968 decade, users would have paid an additional \$4.5 billion. This \$8.6 billion savings over the \$55.5 billion the users actually paid occurred during a period when huge capital outlays were required, first for the postwar piston fleets and then beginning in 1958 for the jet fleets.

Even though air cargo still generates a relatively small portion of air carrier revenues, reductions in air freight rates have also been significant. Had air freight users in the 1949 to 1958 period continued to pay 1948 rates, an additional \$441 million in cargo expenditures would have been required over the \$1.2 billion actually paid. Similarly, if the users from 1959 through 1968 had continued to pay 1958 cargo rates, they would have paid \$1.2 billion more than the \$4.6 billion they did pay (ref. 2). It is recognized that maintaining 1948 and 1958 rates could have reduced demand. Nonetheless these calculated figures represent reasonable approximations of the probable savings even under reduced demand conditions.

Time Savings

During the past two decades, travel time was also decreasing dramatically. Using 1948 as the base year, about 140 million passenger-hours were saved because of improvements in the air fleet from 1949 through 1958. With the advent of the jets, more than 840 million additional hours were saved between 1959 and 1968 (using 1958 as a base year) (ref. 2). This has amounted to a total of 980 million hours saved by businessmen and pleasure travelers, worth an estimated \$5 billion.

Safer Transportation

Advances in safety have brought about a reduction in the fatality rate from 1.25 deaths per 100 million passenger-miles in 1948 to 0.27 deaths per 100 million passenger-miles in 1968 for scheduled service of the U. S. certificated air carriers (ref. 2). If the 1948 fatality rate had persisted over the next 20 years, an additional 7,705 fatalities would have been expected over the 3,312 that did occur. These improvements in safety occurred during a period when the fleet doubled, aircraft departures more than doubled, and entirely new aircraft came into service.

Business Stimulation

The growth of civil aviation has helped shape the pattern of commercial and industrial activity in this country over the past 20 years. Fast, efficient air travel and communications have made possible new techniques of industrial management and control. Since World War II, a fundamental change in American business has occurred – decentralization of economic activity, coupled with the centralization of management. Businesses organized in this way would be difficult to manage without fast personal travel. The growth of large, diversified corporations, in particular, would have been impeded without civil

aviation. The success of this type of organization is dependent upon the ability of a central core of high management talent to move rapidly to widely dispersed operations, when they are needed. For example, the Apollo Program involved 20,000 contractors, subcontractors, and suppliers, and almost 400,000 non-Government workers in all 50 states. Without air transportation, it would have been necessary to concentrate all of this activity around a limited number of scientific and academic communities on the East and West Coasts.

Civil aviation today is moving many production processes away from the traditional ways of doing business. Increased productivity has been achieved because geographical separation of the stages of production is now possible. U. S.–manufactured electronic parts, for example, are assembled in Puerto Rico to utilize lower labor costs. IBM computer systems units are routinely manufactured in different parts of the country and assembled into a functioning system at the customer's facility. All such processes depend heavily on air transportation.

Air transportation is also reshaping the concepts of moving people and distributing goods. The productivity of management and of highly specialized employees has been increased by reductions in travel time and by more convenient schedules. Highly skilled, nonduplicable resources (e.g., heart surgeons, architects, sports and entertainment figures, Government and business executives) can be more productive with enhanced mobility. Air travel is an integral part of their work patterns; this, in turn, has had its effect on the economy. Many progressive businesses also use air transport to optimize the distribution of goods. Although air cargo rates are high, if all the costs of moving and stocking goods are taken into consideration (the "total distribution cost" concept), air is often a real bargain. Rapid shipment may prevent food from perishing, resulting in the extension of markets. Rapid transport may also eliminate warehousing and stockpiling of inventory. For example, Venezuela Growers Association ships melons by air to New York from December to May, thus extending their market boundaries; producers of women's high-fashion apparel use air cargo extensively to respond to rapid changes in taste and avoid the need for maintaining large inventories that may quickly go out of date. As more companies seek to optimize inventories, warehousing, shipping time, shipping costs, packaging, and handling, it is expected that air shipment will expand, providing new stimulation to business.

The United States is shifting from a hard-goods society to a service-oriented society. Today, employment is split about 50–50 between goods and services, but it is anticipated that by 1980, seven out of every ten people will be employed by service industries. Tourism and Government are two examples of service-oriented activities. Analysis of Department of Commerce input/output data on the U. S. economy shows that air transportation contributes twice as much to the value of output of the service industries as it contributes to any other sector (ref. 9). The service industries are very labor-intensive and employ a broad cross section of socioeconomic classes. It is important, therefore, to look not only at the direct benefits brought by civil aviation to business in terms of increased productivity, but to recognize that large spinoffs in terms of additional employment and productivity are generated by civil aviation.

BENEFITS TO THE REGIONS

The Federal Government has distributed over \$1.2 billion in aid for both commercial and general aviation airport development since the inception of the Federal Aid to Airports Program in 1946 and \$2.1 billion for the development and implementation of the national airways system. While the allocation of these funds has been made with little understanding of their impact on the social and economic development of the regions affected, the few studies that have been made indicate that significant social and economic benefits accrue from airport development, both in metropolitan and rural areas.

A recent study (ref. 10) considered the economic impact to be expected by 1975 from the addition of new maintenance facilities due to increased service requirements for both American and Trans World Airlines at Los Angeles International Airport. The following benefit projections resulted:

- 23,000 additional jobs (direct and indirect).
- $86.2 million in additional construction.
- A additional $630.2 million per year in purchases of goods and services.

Based on 1975 projections (ref. 11) for the Dallas/Fort Worth area, analyses indicate a similar impact from the airport on the economic health of North Central Texas:

- 46,612 employees.
- $600 million per year economic impact (direct and indirect) in terms of purchases of goods and services.

A recent study (ref. 12) by the Economic Development Administration, U. S. Department of Commerce, on the growth ratio of 34 pairs of cities showed that airports can significantly affect the economy of medium-sized communities as well. The members of each pair were reasonably close geographically and had approximately the same socioeconomic characteristics with the exception that one had scheduled airline service and the other did not. The differences in the number of new manufacturing jobs per capita over the 1958-1963 period were calculated as a measure of growth for the airline and nonairline groups. The study concluded that civil aviation can have a positive influence on the growth of manufacturing in a city, and that the extent to which a city can realize the full benefits of air service depends upon its size, its proximity to the interstate highway system, its regional location, the growth of established industry in the region, and the mileage from center city to the airport.

Although the results of this study support the hypothesis that civil aviation can have an impact on a region's economic development, a gap still exists in relating civil aviation's role to the development process and in understanding the supporting factors that appear to determine the extent and nature of its effect on this process.

To the casual observer, evidence of civil aviation's influence on regional development is perhaps more readily visible in less-developed areas than in large metropolitan complexes. A study (ref. 13) was made of Ohio's County Airport Development Program. Under this program the State granted $100,000 toward the construction or expansion of airports to each of 50 Ohio counties. It was anticipated that each new general aviation airport would serve the travel market between its county and other destinations, and, more importantly, that each airport would stimulate increased economic activity within its environs, thus furthering the county's economic development. Between 1966 and 1970, 62 new airports were constructed under this program.

The Ohio Department of Development has traced the following benefits directly to these airports:

- 60,000 new jobs were added.
- An additional $250 million in personal income was generated.
- Enough new trade was generated to support 200 additional retail establishments.
- 1,500 manufacturing firms were added or expanded.
- An additional $1 billion in capital was invested.
- Within one year after an airport was completed, the value of the adjacent land had doubled.
- Twenty new industrial parks were established.

The study concluded that "the installation of airports, capable of accommodating large business aircraft, is likely to generate an improved economic base to the communities which surround each facility" (ref. 13).

A study (ref. 14) by the FAA of five general aviation airports supported by the Federal Aid to Airports Program also indicated that "accelerated economic growth" can result from airport development if other community conditions are favorable. The FAA study credited the airports in its sample with being the catalysts for substantial increases in the census index of value added by manufacture, wholesale and retail trade, and services recorded in each community after the construction of the airport.

A recent Air Transport Association study of the effect of air transportation on the economic development of South Dakota (ref. 15) and the FAA study of general aviation airports cited above revealed that where new airports were *not* built, farm mechanization had been a major factor contributing to the decline of population, labor force, and employment in the rural areas surrounding the communities. Where new airports were added, however, the rural labor force was retained by the increased business and industrial job opportunities in the community. This has benefited new industry by providing a source of skilled and semi-skilled labor in nonurban areas.

The influence of civil aviation on development under different political, social, and economic conditions needs further investigation. The Federal Government influences regional development through its role in the distribution of airport development funds, whether there is such an intention or not. It therefore has an obligation to assess this influence and to take it into consideration in the future allocation of funds. The Economic Development Administration (EDA) has funded a total of 43 airport-related projects in economically depressed areas at a cost of over $25 million, and the Department of Housing and Urban Development (HUD) funds have been widely used for community planning and development, including some airport planning. Both EDA and HUD have evaluated the effects of their programs under varying social and economic conditions, and have already devoted some attention to the role of civil aviation, particularly with reference to its influence on the development of regional growth centers.

BENEFITS TO THE NATION

Gross National Product (GNP) contribution and employment are general benefits in the same way that any business activity exerts positive influence on the economy. Balance of trade, defense preparedness, and cultural understanding are national benefits to which civil aviation offers a unique contribution.

Gross National Product

Civil aviation has been a significant contributor to the Nation's economy. Rising from 0.2% in 1949 to 1.0% in 1969, civil aviation's contribution to the GNP is now growing at a rate two to three times faster than the economy as a whole (refs. 3, 7). (In 1963 the communications industry contributed 1.6% and the largest industry group – new construction – contributed 4.6% (ref. 16).) Over the jet era, the civilian portion of aerospace (commercial and general aviation together) has grown at 9.5% per year to a $3.5 billion contribution, and the air carriers have grown at 13.3% per year, to $6.3 billion (including direct and indirect contributions to GNP) (refs. 3 and 7).

The contribution of civil aviation to the economy is significant. Its acceptance by the American public, as shown by its phenomenal growth, testifies to its importance.

Employment

Civil aviation (civil aerospace plus air carriers) is one of the largest employers in the Nation (ref. 17).

In 1968, direct plus induced employment was 390,000 for civilian aerospace and 440,000 for air carriers, averaging about a 9% growth rate for both sectors (refs. 3, 7). The economic turndown in 1970 has resulted in layoffs in both groups. Civilian aerospace employment is expected to drop 20% to 312,000 and that of the air carrier sector to decline 2% to 431,000 by the first part of 1971 (ref. 18). The technical talent of civilian aerospace in particular is an important asset to the defense of our country. Preservation of this highly skilled scientific, engineering, production,

and management talent is a necessary element in the maintenance of a high technology level.

Balance of Trade

The favorable balance of trade maintained by the aviation industry over the years is a unique asset – one that probably could not be replaced by another industry if the aviation dollars were invested elsewhere. Today, over 76% of the existing free-world airline fleet is the product of U. S. manufacturers (ref. 19). In 1969, this accounted for a net balance of $1.77 billion by civil aerospace manufacturers, with an historical growth rate of 9.7% (ref. 20).

Currently, 57% of the free-world air traffic is carried by U. S. airlines (ref. 21). At the same time, since foreign airlines carry more U. S. passengers than U. S. airlines carry foreign passengers, a consistently negative balance-of-payments position exists for the U. S. airlines. Historically, this deficit has grown at 1.4% per year. The strong positive balance maintained by the aircraft manufacturers more than offsets this, however, producing a net $1.5 billion balance by the entire civil aviation industry (based on refs. 3, 7, 20, 22). This is nearly equal to the total U. S. favorable trade balance in 1969.

Defense Preparedness

The civil aviation industry has also become an important element in preparedness for the national defense. Over the past five years (under charter operations for the Military Airlift Command), civil aviation has moved approximately 11.2 million people and 0.7 million tons of cargo (see Table 7.3). This was over 90% of all military airlift passengers and 25% of all military air cargo (ref. 23).

As of December 1970, over 435 civil passenger and cargo aircraft owned by 24 U. S. commercial airlines were committed to the Civil Reserve Air Fleet (CRAF). They become available to the Department of Defense for augmentation airlift during emergencies. It has not yet proved necessary to mobilize this reserve fleet because the Military Airlift Command's requirements for charter operations have been met by airlines participating in the CRAF program without mobilization. The present reserve fleet of commercial aircraft can provide, however, on 24 hours' notice, the capability to move over 16 million ton-miles and 59 million passenger-miles per day. It has cost the Government only some $246,000 per year (largely for administrative costs) to ensure this tremendous reserve of capacity and mobility for the armed forces. If it had been

TABLE 7.3. MILITARY AIRLIFT COMMAND CHARTER OPERATIONS

FISCAL YEAR	TOTAL, EXPENDITURES MILLIONS OF DOLLARS	PASSENGERS, THOUSANDS	CARGO, TONS	PERCENT OF TOTAL OPERATIONS[a]	
				PASSENGERS	CARGO
1966	394.2	1,446.5	102,106	90	30
1967	685.0	1,929.0	201,905	91	34
1968	691.4	2,482.3	163,073	91	24
1969	617.2	2,718.8	147,603	93	20
1970	558.0	2,627.0	103,991	91	16
TOTAL	2,945.8	11,203.6	718,678		

[a]Percentage of total Military Airlift Command operations provided by charter.
Source: Ref. 23.

necessary for the Government to purchase these aircraft, it would have cost over $2 billion.

The availability of a large civil fleet and the existence of the organized Civil Reserve Air Fleet greatly augment the national defense capability.

Cultural Exchange

Civil aviation has facilitiated communications between nations, fostering an unprecedented level of cultural exchange. State Department's cultural exchange program and many other educational exchange programs have promoted visits to the United States by foreign representatives of the cultural and academic communities, as well as reciprocal visits abroad by similar U. S. representatives. Air travel has been an important element in this exchange process. Additionally, the low cost of international travel by air has encouraged individuals and groups to travel abroad on pleasure trips.

In the past eight years, 95.3 million people have arrived in or departed from the United States, 82.7 million (87%) by air, with about half of the total number (43.5 million) arriving or departing on U. S. carriers (ref. 24) (Fig. 7.4). During the same period, the number of U. S. students studying abroad rose from 17,000 to nearly 26,000, while the number of foreign students studying in the United States jumped from 57,000 to 135,000 (ref. 25). This great interaction between members of different cultures constitutes an important benefit to the Nation, made possible by aviation. Without civil aviation, the ability of the United States to continue to develop such ties with other nations of the world would be limited.

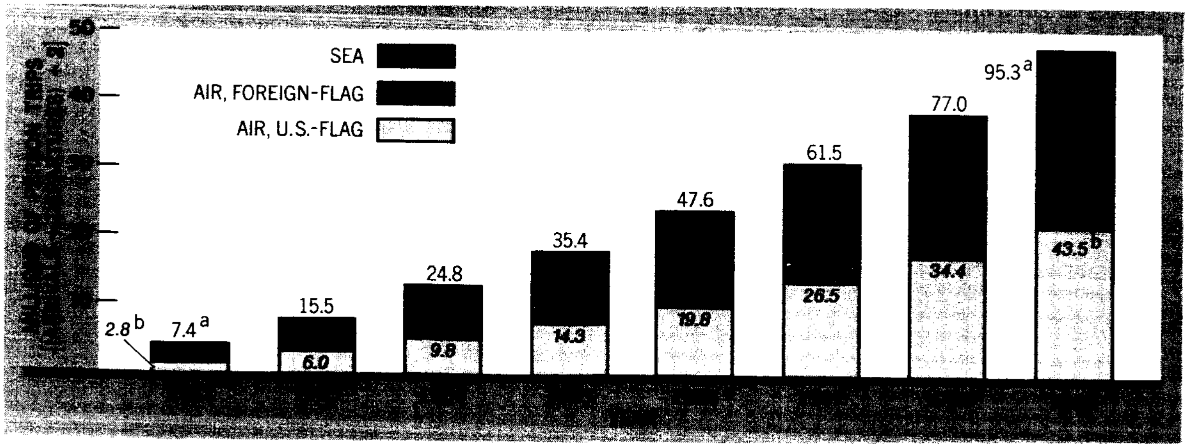
DISBENEFITS

The positive benefits of civil aviation have not been achieved without some undesirable side effects, of which noise and air pollution are the most troublesome.

Noise

The industry has underestimated the importance of noise abatement in the past. Noise reduction has been considered as a source of annoying additional operating costs, to be avoided if possible. With increasing operations, however, the noise problem has generated public reaction to such an extent that:

- New airport location is difficult and in some cases impossible;



Note: Numbers on bars are arrivals + departures.
[a]Cumulative totals in millions of people for 1962–1969.
[b]Cumulative total for people carried on U.S. air carriers.

Figure 7.4. Cumulative arrivals in, and departures from, United States by mode, 1962–1969. *Source: Based on ref. 24.*

- Noise suits have been initiated in some communities;
- The SST was resisted on environmental issues, noise being a major consideration;
- Air carrier takeoff-and-landing procedures are often altered due to public noise complaints;
- Citizen groups are already resisting V/STOL, primarily on the basis of noise (ref. 26).

Concern over noise began to grow rapidly with the introduction of the jets. The noise footprint of the standard Boeing 707 covers an area approximately 30 times that of a four-engine piston aircraft (ref. 27). With the changeover to jets and the great number of flights, the number of people subjected to high noise levels has grown tremendously. In 1958, 100 square miles of land and 1 million people in the United States were within areas with a Noise Exposure Forecast (NEF) of 30 or higher (considered undesirable for residential use). By 1968, this area had grown to 1,300 square miles and contained 15 million people (about 8% of our population) (Fig. 7.5). Unless substantial improvements are made in the system, it is projected that by 1978, the affected land area will grow to 1,800 square miles, encompassing almost 24 million people (ref. 28).

Modifying or replacing engines in existing aircraft ("retrofitting") to reduce noise is costly. For a large four-engine transport, costs range from \$0.7 million (for nacelle treatment) to between \$6 and \$8.6 million (to fit four new quiet engines) (refs. 26, 29). The costs are reflected in markedly increased direct operating costs for the air carriers. Retrofitting must then be carefully weighed against other alternatives such as the purchasing of land buffers and housing noise-insulation programs.

Figure 7.6 shows the first order effects of trade-offs between land purchases and engine retrofit, covering the 1,300 square miles of land presently affected by noise levels of 30 NEF or greater and for an aircraft fleet of 1,000 four-engine transports. If no reductions are made in engine noise, it would cost an estimated \$17 billion (at \$20,000 per acre) to purchase all of the land in the high-exposure area. If engine noise could be reduced by 10 dB, however, the area of land exposed to noise levels of 30 NEF or

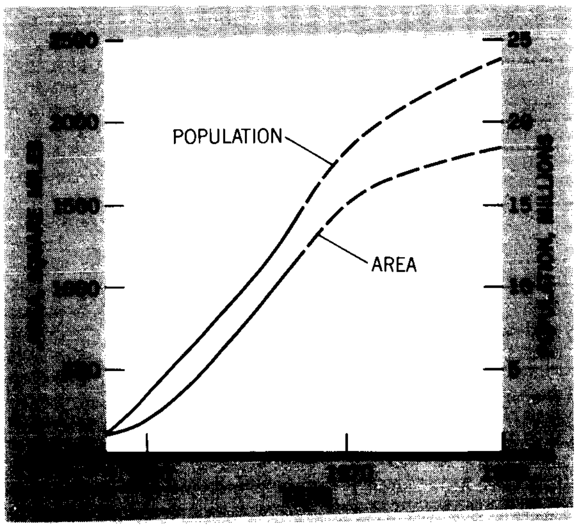


Figure 7.5. Noise-impacted areas and populations (30 noise exposure forecast or higher). *Source: Based on ref. 28.*

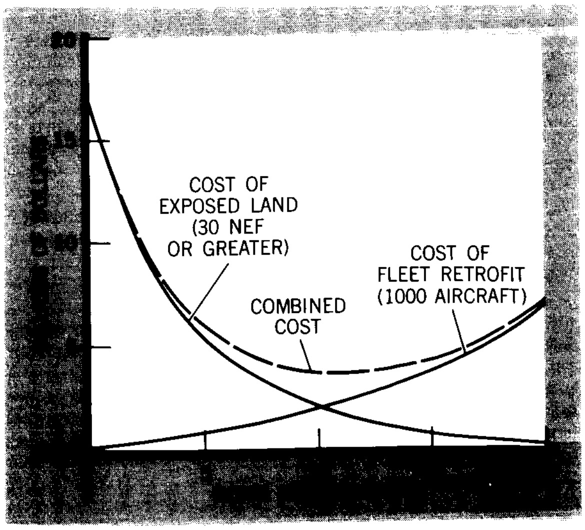


Figure 7.6. Cost of acquiring land versus retrofitting fleet (United States).

greater would be greatly reduced. If, through research and development, engine noise could be reduced by 20 dB, virtually no land beyond the airports would be exposed to noise levels of 30 NEF or greater. (Figure 7.6 does not take into account the additional operating costs incurred through retrofitting or the fact that noise land buffers might be put to later profitable use, since these factors would be significantly different for each case.) The combined costs shown in Figure 7.6 suggests, however, that a combination of land purchase and engine retrofit would produce the most beneficial results. Any reduction in the cost of engine retrofit would weight the choice even more heavily in favor of retrofit. Since engine retrofitting requires the air carrier to pay, and land buffering requires the airport operator to pay, there is a reluctance on the part of both the air carrier and airport operator to take the initiative, in the hope that the other will take the first step.

The social cost of households subjected to excessive noise is difficult to assess. However, the Federal-Aid Highway Act of 1968 (ref. 30) provides a possible precedent and a clue to evaluating this cost. The Act provides for relocation services, allowances, moving and property transfer payments *over and above acquisition payments*. This amounts to $2,500 per household or $625 per person for a family of four. If the Government were to apply a similar cost of $625 per person for "noise rights-of-way," the system-wide social cost would be $9.4 billion to cover the 15 million people presently affected by noise levels of 30 NEF and higher.

Air Pollution

The introduction of the turbine engine lowered air pollution trends for several years, but the number of new aircraft introduced since has more than offset the previous gains. Even in areas of heavy contamination from other sources, the visible emissions from aircraft today cause community antagonism. The smoke is in the process of being eliminated. The invisible emissions, however, are the more serious pollutants.

Even though aircraft contribute only a very small percentage to the total, there are "hot spots" of pollution found around many airports. An estimated 2.3 billion pounds of pollutants were emitted by aircraft in commercial operation in 1970, 0.5 billion pounds of this in the vicinity of airports (ref. 31). R&D has been successful, nevertheless, in reducing pollutant emission. A medium-range turbofan aircraft produces 8.6 pounds of pollutant per 1,000 pounds of fuel on takeoff, while a piston aircraft emits 1,442 pounds per 1,000 pounds of fuel on takeoff (the weight is high because the fuel combines with air to form oxide compounds) (ref. 31). Although civil aviation contributes significantly fewer pounds of pollutants per passenger-mile than the automobile, aviation must continue to do its part with all other industries to preserve and restore the environment.

In 1967, 1,980,000 passengers flew between Washington, D. C. and New York (ref. 32). Assuming that medium-range fanjets were used, each carrying 51 passengers (56% load factor), 3 million pounds of pollutants were emitted by the airplanes. If these passengers had traveled by auto (assuming 1.5 passengers per vehicle and 45 miles per hour speed), 36 million pounds of pollutants would have been emitted. In this example, the automobiles would have contributed over 10 times the emissions contributed by the airplanes.

As auto emissions are decreased and air operations continue to increase, aircraft pollution emission may be expected to exceed the urban background level. Public opposition to aviation, induced by air pollution, can be expected to grow unless solutions are aggressively pursued. Minimization of noise and air pollution will help restore public confidence in the positive contribution that civil aviation can make to our Nation's future.

Other Disbenefits

As with any massive construction program, new airports can induce other social disbenefits

that must be considered when assessing any aviation proposals.

- Public opposition due to airport siting will become an increasing problem in some cases where city-center VTOL or STOL service is desired.
- The airport is a major activity center that impacts upon roads and services in the immediate area, which can add to congestion. Its presence stimulates placement of additional businesses around its periphery, which can contribute even more to congestion.

PROJECTIONS OF PRODUCTION, EMPLOYMENT, AND BALANCE OF TRADE

Turning from an historical look at civil aviation, one can examine the implications which the forecast growth in air travel has for the production and sale of large civil air transports. With the expected growth in demand, the free-world fleet of large civil air transports will grow from 5,100 aircraft today to about 8,300 aircraft by 1985 (ref. 19). The increase, along with the replacement of retired aircraft, will provide a large potential market for U. S. aviation manufacturers.

In the near future, sales will be dominated by existing technology, embodied in aircraft in or nearing production. Sales of improved and "stretched" versions of these aircraft are projected to continue until 1983. For these existing technology aircraft – for example, the B–747, L–1011, and DC–10 – the United States may expect to be the sole source. For new technology aircraft, the U. S. share of the market is far from assured. Beginning with the Concorde and standard wide-body twin-jets, and continuing with stretched twin-jets, the SST and the advanced Concorde, STOL or VTOL feeder jets, and advanced medium-range transports, new technology is expected to account for an increasing proportion of new aircraft sales.

Figure 7.7 shows the projected dollar value of total production of large civil air transports (Projection 1), of the estimated U. S. share of both existing and new technology sales (Projection 2), and of the U. S. share of existing-technology sales alone (Projection 3). Projection 2 assumes that foreign manufacturers will increase their share of the new technology market. They will increasingly meet the needs of the foreign air carriers, which, in turn, will increase their share of the air travel market relative to U. S. air carriers.

At the 1983 peak, U. S. capture of the entire world market (Projection 1) would triple its output over 1970. U. S. capture of the projected share (Projection 2) would easily double U. S. output. But by 1983, the share of U. S. output (Projection 3) based on existing technology alone would be only one-fifth of its 1970 value. In the following year, with the end of sales of stretched 747's and the wide-body tri-jets, the U. S. share of the market would disappear.

For Projection 2 (a market shared by the United States and, increasingly by foreign manufactures), the 1971-1985 cumulative sales of new-technology aircraft by the United States

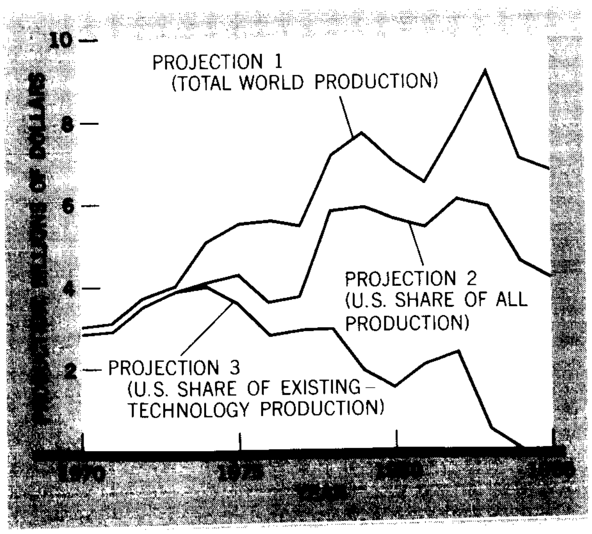


Figure 7.7. Forecast commercial transport production. *Source: Based on ref. 19.*

would be $34.5 billion. During the same period, U. S. sales based on existing technology would be expected to total $35.0 billion (Fig. 7.8).

Employment follows a pattern similar to production (Table 7.4). With the United States attaining its share of both new- and existing-technology sales, primary and indirect employment generated by new large civil air transports alone will be 214,000 by 1980.

These projections emphasize once again how necessary continuing R&D is to the survival and growth of the U. S. civil aerospace industry.

The need for R&D in sustaining the balance of trade is even more marked (Figs. 7.9 and 7.10). For Projection 2 (a U. S.- and foreign-shared market), the 1971-1985 total U. S. trade balance would be $21.8 billion. Should the United States fail to pursue new technology, then a drop in sales, to the extreme of Projection 3, would occur as shown in Figure 7.10, with sales finally falling to zero by 1984. In such a case, if U. S. carriers *imported new-technology aircraft*, the balance of trade would fall to zero by 1975 – nine years earlier. A 1971-1985 cumulative deficit of $12.7 billion in balance of trade would result.

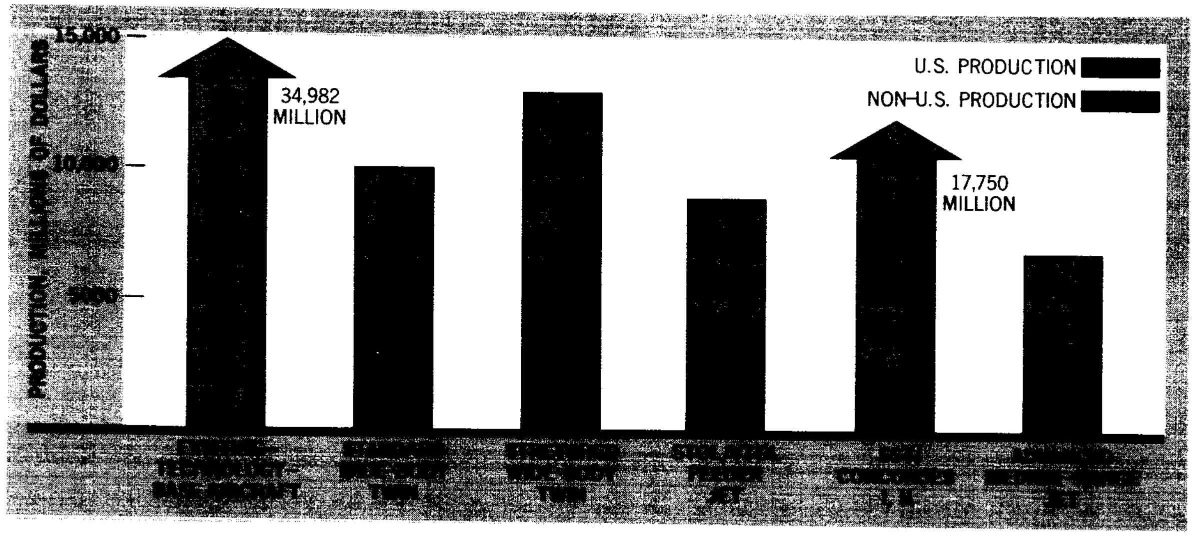


Figure 7.8. Cumulative commercial transport production, 1971–1985. *Source: Based on ref. 19.*

TABLE 7.4. PRIMARY AND INDUCED EMPLOYMENT (THOUSANDS)

AIRCRAFT TYPE	PEAK YEAR	PRODUCTION YEARS	U.S. PRODUCES A SHARE			U.S. PRODUCES ALL		
			AVERAGE	PEAK	CUMULATIVE	AVERAGE	PEAK	CUMULATIVE
EXISTING TECHNOLOGY-BASE AIRCRAFT	1974	70-84	150	225	2,098	153	227	2,142
STANDARD WIDE-BODY TWIN	1976	73-80	30	44	210	78	88	553
STRETCHED WIDE-BODY TWIN	1983	77-85+	42	86	333	90	171	719
STOL/VTOL FEEDER JET	1982	77-85+	34	59	278	58	97	462
SST/CONCORDE I, II	1979	78-85+	102	151	813	102	151	813
ADVANCED MEDIUM RANGE JET	1983	82-85+	58	61	175	115	119	346

Source: Based on refs. 17, 19.

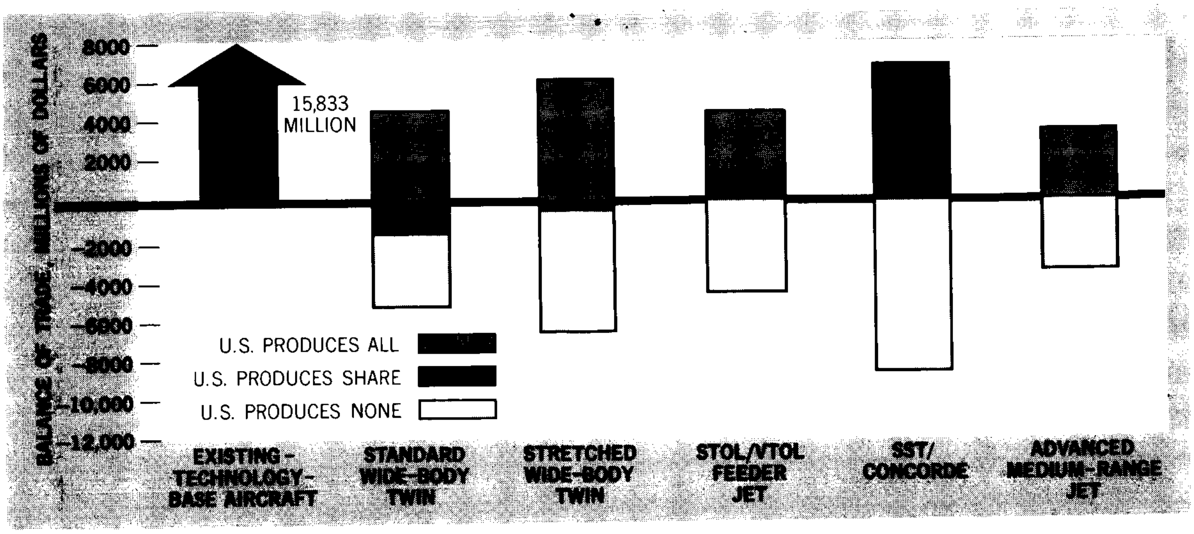


Figure 7.9. Cumulative balance of trade, new and existing technology, 1971–1985. *Source: Based on ref. 19.*

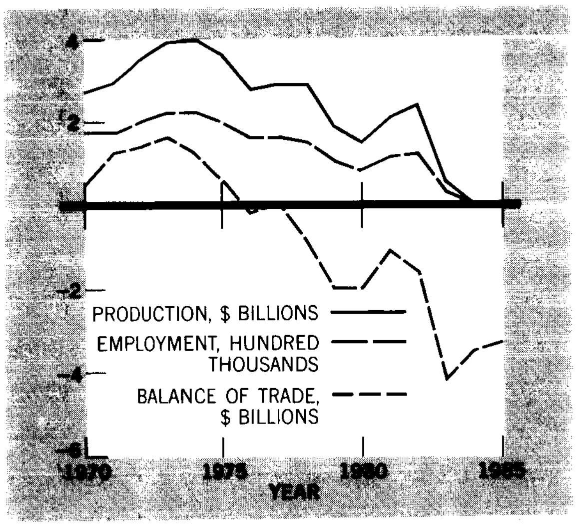


Figure 7.10. Yearly projections: United States captures no new commercial transport markets. *Source: Based on ref. 19.*

Thus, although the possibility of Projection 3 is remote, it must be remembered that balance of trade acts as an early warning indicator of the health of the civil aviation industry.

If the United States follows a course approximating Projection 2, aircraft production in dollars will show a modest 5.7% annual increase, and employment a 4.7% annual increase, compared with the recent historical rates of 9.5 and 8.4%, respectively. The balance of trade will remain relatively level for the 1971-1985 period.

CONCLUSIONS AND RECOMMENDATIONS

- R&D has contributed tangibly to productivity increases, which, in turn, can be translated into benefits. Introduction of jet-powered aircraft succeeded in increasing the productivity of the system by a factor of three.
- Benefit analyses trace most of the advances to the vehicle. The majority of future productivity increases, and hence benefits, are expected to come primarily from achieving a better balance among all the elements that make up the air transport system.
- Substantial benefits from civil aviation have been passed on to the user. Approximately $8.5 billion in passenger-fare and $1.6 billion in cargo-rate savings have been realized due to advances in the aviation system over 20 years. An estimated 7,700 fatalities have been avoided due to the high degree of safety built into the present-day civil aviation system.

- Many of the benefits extend far beyond the direct user of the system; they encompass regional development, business stimulation, balance of trade, improved cultural understanding, and defense preparedness.
- Civil aviation is an essential element needed to maintain a high-technology economy. Better distribution of scarce talent and high-value goods will help the United States maintain its economic strength. As the economy moves in a service-oriented direction, reliance on civil aviation will increase.
- Airport development has a catalytic effect on the economy of a region. It is therefore recommended that HUD and DOT/FAA engage in a joint program to gain a better understanding of the role and impact of civil aviation in regional development. This can lead to unification and clarification of objectives between the two agencies.
- Balance-of-trade data can serve as a sensitive early-warning indicator that the domestic civil aerospace industry will lose its vitality unless new programs are initiated.
- Noise and air pollution are among the greatest disbenefits impeding the growth of civil aviation today. Over 15 million people in the United States are affected daily by unacceptable noise levels, with an estimated social cost of $9.4 billion. A combination of retrofitting and land acquisition, as well as better land-use programs, is required to effectively solve this problem. Although air pollution output per air passenger is an order of magnitude less than auto pollution output per person, air pollution "hot spots" in the vicinity of airports are appearing in certain metropolitan areas. Their appearance should serve as an early indicator that public opposition to aviation-induced air pollution can be expected to grow unless solutions are aggressively pursued. Solution of these problems is required not only to help eliminate congestion in the system, and help meet projected demand, but also to allow an uninterrupted stream of benefits and to improve the quality of life.

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8. APPENDIXES

Appendix A: List of Illustrations

Appendix B: List of Tables

Appendix C: Glossary

AIR CARGO. All revenue air traffic other than passengers; includes freight, express, mail, and passenger baggage in excess of free allowance.

AIR CARGO TRAFFIC. Freight, express, and mail carried by fixed-wing aircraft or helicopters, measured in revenue ton-miles.

AIR CARRIER. Aircraft operators certificated by the Federal Aviation Administration to transport persons, property, and mail by air.

AIRCRAFT MILES OR PLANE MILES. The miles (airport-to-airport distances) for each inter-airport flight actually completed, whether or not performed in accordance with the scheduled pattern. For this purpose, operation to a flag stop (stop only on request) is a flight completed, even though a landing is not actually made.

AIRCRAFT OPERATION. An aircraft arrival at or departure from an airport with FAA airport traffic control service. There are two types of operations – local and itinerant. Local operations are performed by aircraft that:

1. Operate in the local traffic pattern or within sight of the tower.
2. Are known to be departing for, or arriving from flight in local practice areas located within a 20-mile radius of the control tower.
3. Execute simulated instrument approaches or low passes at the airport.

Itinerant operations:

All aircraft arrivals and departures other than local operations.

AIRCRAFT REVENUE HOURS. The airborne hours in revenue service, computed from the moment an aircraft leaves the ground until it touches the ground again.

AIRCRAFT SPEED. The average speed of an aircraft in statute miles per hour, while airborne, in terms of great circle airport-to-airport distance.

AIRPORT CAPITAL INVESTMENT. The estimated replacement value of existing airports; includes land, runways, taxiways, terminals, roads, and parking facilities. Projected airport capital investment is the cost (for the Joint Study, in 1968 constant dollars) of the projected number of airports by type, including the cost of land, runways, terminals, parking areas, and the replacement cost of existing airports.

AIRPORT OPERATION AND MAINTENANCE (O&M) COSTS. Total costs associated with the operation and maintenance of an airport and related facilities. These costs do not include charges for debt retirement or return on investment.

AIRPORTS. *See* NATIONAL SYSTEM OF AIRPORTS.

AIR ROUTE TRAFFIC CONTROL CENTER. A facility established to provide air traffic control service to IFR (Instrument Flight Rules) flights operating within controlled airspace, principally during the enroute phase of the flight.

AIR TAXI OPERATOR. One of a class of air carriers operating aircraft having a maximum gross takeoff weight of 12,500 pounds or less and engaging in a wide variety of nonscheduled and scheduled passenger and cargo transportation services (*see* COMMUTER AIRLINES).

AIR TRAFFIC CONTROL SYSTEM. As used in this report is synonymous with "airways" and includes enroute control and services, terminal area control and services, flight services, airspace allocation and rules, enroute navigation, and landing aids.

AIR VEHICLE CAPITAL INVESTMENT. The estimated replacement value of the inventory of aircraft, spares and repair parts, and supporting ground equipment. Projected capital investment is the total cost (in 1968 constant dollars) of the various types of aircraft and associated ground-support equipment in a forecast fleet mix.

AIR VEHICLE OPERATION AND MAINTENANCE (O&M) COSTS. Total of direct and indirect operating costs by mission and type of vehicle, excluding interest expense and aircraft landing fees.

AIRWAYS. As used in this report, airways includes enroute control and services, terminal area control and services, flight services, airspace allocation and rules, enroute navigation and landing aids (*see also* AIR TRAFFIC CONTROL SYSTEM).

AIRWAYS CAPITAL INVESTMENT. The estimated replacement value of the facilities and equipment used in the National Airspace System. Projected capital investment is the estimated cost (in 1968 dollars) to acquire and install the facilities and equipment envisioned in the FAA National Airways System Plan – Ten Year Plan 1971–1980, plus its expansion recommended by the ATCAC.

AIRWAYS OPERATION AND MAINTENANCE (O&M) COSTS. Total costs required to operate and maintain the National Airspace System as envisioned in the FAA National Aviation System Plan – Ten Year Plan 1971–1980, plus the expansion recommended by the Air Traffic Control Advisory Committee ATCAC.

ALL–CARGO AIRCRAFT. An aircraft designed or converted to carry freight, express, etc., not passengers.

ALL SERVICES. The total of scheduled and nonscheduled services.

ATA. Air Transport Association of America.

ATC. Air Traffic Control.

ATCAC. Air Traffic Control Advisory Committee, Department of Transportation (the Committee's report was issued December 1969). Sometimes referred to as the Alexander Committee.

AVAILABLE SEAT–MILES. The aggregate of the products of the aircraft miles flown on each inter-airport flight multiplied by the number of seats available on that flight, representing the total passenger-carrying capacity offered.

AVAILABLE SEATS. The number of seats installed in an aircraft (including seats in the lounges) exclusive of any seats not offered for sale to the public by the carrier, and inclusive of any seat sold.

AVAILABLE SEATS PER AIRCRAFT. The average number of seats available per aircraft for sale to passengers, derived by dividing the total available seat-miles by the total aircraft revenue miles in passenger services.

AVAILABLE TON–MILES. The aggregate of the products of the aircraft miles flown on each inter-airport flight multiplied by the available aircraft capacity (tons) for that flight, representing the traffic-carrying capacity offered.

AVERAGE PASSENGER TRIP LENGTH. Calculated by dividing the number of revenue passenger-miles by the number of revenue passenger originations. Hence, it gives one-way trip length.

BREAK–EVEN LOAD FACTOR. That load factor required for revenue to equal expenses.

CAB. Civil Aeronautics Board.

CARGO. *See* AIR CARGO.

CARGO ORIGINATIONS (TONS). Revenue tons of mail, express, and freight placed in transit in scheduled service at the airport from which originally dispatched in the carrier's operations. Shipments of this traffic moving on interline routings are counted as originating tons on each of the carriers participating in the shipment.

CARGO TON–MILES. The ton-miles of freight, express, mail, and excess baggage (*see* TON–MILES).

CBD. Central Business District.

CATEGORY I WEATHER. Weather allowing a forward visibility of 1/2 mile. The pilot should be able to see the runway from an altitude not in excess of 200 feet.

CATEGORY II WEATHER. Weather allowing a forward visibility of 1/4 mile. The pilot should be able to see the runway from an altitude not in excess of 100 feet.

CATEGORY III WEATHER. Runway effectively not visible from any altitude and all landing decisions are left to the pilot. Category III breaks down into three subcategories, IIIA, IIIB, and IIIC, as follows:

IIIA. Forward visibility is 700 feet, a distance sufficient for a landing abort.

IIIB. Forward visibility is 50 feet, a distance sufficient to permit taxiing.

IIIC. Zero forward visibility.

CERTIFICATED ROUTE AIR CARRIER. One of a class of air carriers holding certificates of public convenience and necessity, issued by the CAB, authorizing the performance of scheduled air transportation over specified routes and a limited amount of nonscheduled operations. This general carrier grouping includes the all-purpose carriers, the all-cargo carriers, and comprises all of the airlines certificated by the CAB, except the supplemental air carriers.

COMMERCIAL OPERATOR. One of a class of air carriers operating on a private for-hire basis, as distinguished from public or common air carrier, holding a commercial operator certificate issued by the Administrator of the FAA authorizing the operation of aircraft in air commerce for the transportation of goods or passengers for compensation or hire.

COMMON CARRIER. A transportation business that offers its services for public hire. Includes airlines, railroads, buslines, trucklines, and watercarriers. Excludes contract carriers and nontransportation companies and the public at large who provide transportation for themselves.

COMMUTER AIRLINES. Air taxi operators who perform, pursuant to published schedules, at least five round trips a week between two or more points.

CONTROLLED AIRSPACE. Airspace containing aircraft flying under either VFR or IFR. It starts at some altitude above the ground and extends up to Positive Controlled Airspace. In terminal area control zones, it extends to the ground.

CONTROLLED VISUAL FLIGHT RULES (CVFR). Visual flights in which avoidance of collision with all other aircraft is assured by the ATC system. To enable the ATC system to carry this out, CVFR flight is restricted to Positive Control Airspace.

CTOL. Conventional TakeOff and Landing.

DIRECT OPERATING COSTS. Expenses that apply directly to the operation of an airline's aircraft. The main categories are flying operations, maintenance of flight equipment, and depreciation of flight equipment.

DISBENEFIT. Anything that is disadvantageous or not for the good of a person or thing; a negative benefit.

DOC. Direct Operating Costs.

DOD. Department of Defense.

DOMESTIC SCHEDULED SERVICE. Transport service operated over an air carrier's certificated routes, within the territory of the United States (*see* SCHEDULED SERVICE).

DOT. Department of Transportation.

EFFECTIVE PERCEIVED NOISE LEVEL, IN DECIBELS (EPNdB). The effective perceived noise level (EPNL) is a modification of the perceived noise level (PNL) to account for the effect of the pure tones of high-bypass-ratio engines and the effect of the flyover period of an aircraft.

ELIGIBLE AIRCRAFT. An aircraft with a current airworthiness certificate that, through a periodic or progressive aircraft inspection, has been renewed within the past 12 months.

ENPLANED PASSENGERS. Passengers boarding an aircraft, including originating, stopover, and transfer passengers, for both scheduled and nonscheduled service.

FAA. Federal Aviation Administration.

FEEDER SYSTEM (of Airports). *See* NATIONAL SYSTEM OF AIRPORTS.

FLIGHT. The operation of an aircraft from takeoff to landing (*see* OVERALL FLIGHT STAGE LENGTH).

FTL. Fast Transit Link.

GENERAL AVIATION AIRCRAFT. All civil aircraft except those classified as air carriers.

GNP. Gross National Product.

HELICOPTER CARRIERS. Domestic certificated route air carriers employing helicopter aircraft for their primary operations.

ICC. Interstate Commerce Commission.

IFR. Instrument Flight Rules.

ILS. Instrument Landing System.

INDIRECT OPERATING COSTS (IOC's). All airline operating costs, other than direct operating costs.

INTERMITTENT POSITIVE CONTROL (IPC). A system that can reliably and accurately provide an air traffic control center with identity, position, and altitude information on all suitably equipped aircraft within designated portions of the airspace. The ATC computer, through a data link, can automatically advise aircraft of threats because of other aircraft, weather, airspace boundaries, and surface obstacles.

IR&D. Independent Research and Development performed by private companies. In certain cases IR&D costs are allowable overhead charges on Government procurement contracts and are thus reimbursed by the Government.

ITINERANT AIRCRAFT OPERATION. *See* AIRCRAFT OPERATION.

L/D. Lift-Drag ratio.

LOAD FACTOR (PASSENGER). The percentage of saleable seat-miles actually sold in scheduled service (passenger-miles ÷ saleable seat-miles X 100).

LOCAL AIRCRAFT OPERATIONS. *See* AIRCRAFT OPERATION.

LOCAL SERVICE CARRIERS. Certificated domestic route air carriers operating routes of lesser density between the smaller traffic centers and between these centers and principal centers.

LONG–TERM DEBT. The face value or principal amount of debt securities issued or assumed by the air carrier and held by other than associated companies, which has not been retired or cancelled and is not payable within 12 months of balance sheet date.

M. Mach number.

NACA. National Advisory Committee for Aeronautics (Federal aeronautical research agency that was the predecessor of the National Aeronautics and Space Administration).

NASA. National Aeronautics and Space Administration.

NATIONAL SYSTEM OF AIRPORTS. All airports except those of local interest (airports designed to attract industry, enhance prestige, etc.) and military airports except those in joint use. The National System of Airports is broken down into the following major subdivisions based on the number of annual enplaned passengers:

Primary System. More than one million enplaned passengers.

Secondary System. 50,000 to one million enplaned passengers.

Feeder System. Less than 50,000 enplaned passengers.

Each of the above subdivisions is further subdivided into high-, medium-, and low-density airports based on the annual number of aircraft operations. For example, a high-density airport in the primary system has more than 350,000 aircraft operations annually, while a high-density airport in the feeder system has more than 100,000 annual operations.

NECTP. Northeast Corridor Transportation Project.

NOISE EXPOSURE FORECAST (NEF). A factor used to measure the effect of aircraft noise on residential or other communities. NEF takes into account the effective perceived noise level (EPNL) and – with different weightings – the average number of take-offs, or landings, by day and by night.

NONSCHEDULED SERVICE. Revenue flights that are not operated on regular scheduled service, such as charter flights and all non-revenue flights incident to such flights.

OHSGT. Office of High-Speed Ground Transportation of DOT.

OPERATING EXPENSES (COSTS). Expenses incurred in the performance of air transportation. Includes direct aircraft operating expenses and ground and indirect operating expenses.

OPERATION AND MAINTENANCE (O&M) COSTS. *See* AIR VEHICLE, AIRPORT, AIRWAYS O&M COSTS.

ORIGINATING TONS. *See* CARGO ORIGINATIONS (TONS).

OVERALL FLIGHT STAGE LENGTH. The average distance covered per aircraft flight in revenue service, from takeoff to landing, including both passenger/cargo and all-cargo aircraft. Derived by dividing the overall aircraft miles flown in revenue services by the number of overall revenue departures performed.

PASSENGER–MILE. One passenger transported one mile. Passenger-miles are the summation of the products of the aircraft-miles flown on each interairport flight multiplied by the number of passengers carried on that flight.

PERSON–TRIP. One person on one round trip from home to a place at least 100 miles away or staying overnight and returning (as used in this report).

PNdB. Perceived Noise in Decibels.

POSITIVE CONTROLLED AIRSPACE (PCA). Exists above 18,000 feet in the northeastern portion of the United States and above 24,000 feet in the remainder of the country. In PCA, all aircraft are under IFR control and the ATC system provides separation service between all aircraft.

PRICE ELASTICITY OF DEMAND. The extent to which changes in air fares and rates will produce changes in traffic volume.

PROXIMITY (PILOT) WARNING INDICATOR (PWI). An airborne device whose function is to warn a pilot of the proximity of other aircraft. It may also provide other information to assist the pilot in evaluating the situation, such as relative bearing and bearing rate of other aircraft, relative altitude, range, or combinations of these parameters.

R&D. Research and development; includes R&T (see below) and development. Development is the application of technology to the design and fabrication of specific components subsystems, systems, or processes, and to the testing and evaluation of these articles or processes with the intent to go into production of operational articles. This part of the R&D process is sometimes referred to as prototype development.

R&T. Research and Technology – basic and applied research. *Research* (sometimes referred to as basic research) is a discipline-oriented activity directed toward an increase in knowledge in the physical, biological, or social science. *Technology* (sometimes referred to as applied research) is the application of knowledge to arrive at techniques, design data, or design criteria, or to demonstrate the feasibility of a concept with no intent to go into quantity production of operational articles.

RETURN ON EQUITY. The ratio (expressed as a percentage) of (a) net income after special items to (b) stock holder equity.

RETURN ON INVESTMENT (ROI). The ratio (expressed as the percentage of (a) net income after special items, but before interest expense, to (b) total investment (*see* TOTAL INVESTMENT).

REVENUE PASSENGER–MILE (RPM). One revenue passenger transported one mile (*see* PASSENGER–MILE).

REVENUE PASSENGER ORIGINATIONS. The number of revenue passengers boarding aircraft at the points of initial enplanement with the return portion of a round trip counted separately as an initial operation. Passengers traveling on an interairline ticket are counted as an initial origination on each of the carriers in the journey.

REVENUE TON–MILES (RTM). One ton of revenue traffic transported one mile.

SCHEDULED FLIGHT TIME. Elapsed time between departure and arrival as published in Official Airline Guide for best service at peak hours.

SCHEDULED PASSENGER–MILES. Summation of the products of the airport-to-airport distances of all flights scheduled, multiplied by the number of passengers carried (or forecast to be carried) on each scheduled flight.

SCHEDULED SERVICE. Transport service operated over an air carrier's certificated routes, based on published flight schedules, including extra sections and related nonrevenue flights.

STOL. Short Takeoff and Landing.

SERVICES, ALL. Scheduled and nonscheduled transport services.

SST. Supersonic Transport.

STAGE (FLIGHT STAGE LENGTH). The operation of an aircraft from takeoff to landing. Overall flight stage length is the average distance covered per aircraft flight from takeoff to landing. Derived by dividing the overall aircraft miles flown in revenue services, by the number of overall revenue departures performed.

SUPPLEMENTAL AIR CARRIER. One of a class of air carriers holding temporary certificates of public convenience and necessity issued by the CAB, authorizing them to perform passenger and cargo charter services, supplementing the scheduled service of the certificated route air carriers.

TON–MILE. One short ton transported one statute mile. Ton-miles are computed by summation of the products of the aircraft miles flown on each interairport flight multiplied by the number of tons carried on that flight.

TOTAL CAPITAL. Net worth (capital stock, earned, surplus, capital surplus, and contingency reserves) plus long-term debt.

TOTAL INVESTMENTS. Average of five quarterly balances of stockholder equity, long-term debt, and advances from associated companies representing investment.

TRUNK CARRIERS (DOMESTIC TRUNK CARRIERS). This group of carriers operates primarily within the limits of the 48 contiguous states of the United States and the District of Columbia over routes serving primarily the larger communities. Most of the domestic trunks also have international and territorial operations.

UMTA. Urban Mass Transit Administration of DOT.

VFR. Visual Flight Rules.

V/STOL. Vertical/Short TakeOff and Landing.

VTOL. Vertical TakeOff and Landing.

YIELD PER PASSENGER–MILE. Passenger revenues divided by total passenger-miles, expressed in cents per passenger-mile.

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